NORTHEASTERN UNITED STATES WATER SUPPLY STUDY (NEWS)

SOUTHEASTERN NEW ENGLAND STUDY

PRELIMINARY DRAFT ENVIRONMENTAL STATEMENT

NORTHFIELD MOUNTAIN WATER SUPPLY PROJECT
MILLER'S RIVER BASIN WATER SUPPLY PROJECT

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.

NOVEMBER 1972

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"November 1972"
"Southeastern New England Study"

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ENVIRONMENTAL STATEMENT

NORTHFIELD MOUNTAIN WATER SUPPLY PROJECT
MILLER'S RIVER BASIN WATER SUPPLY PROJECT
NORTHEAST WATER SUPPLY STUDY (NEWS)

Prepared By
U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
WALTHAM, MASSACHUSETTS

November 1972

SUMMARY SHEET

NORTHFIELD MOUNTAIN DIVERSION
MILLERS RIVER DIVERSION
NORTHEAST WATER SUPPLY STUDY

(X) Draft ( ) Final Environmental Statement

Responsible Office: U. S. Army Engineer Division, New England, Waltham, Massachusetts

1. Name of Action: ( ) Administrative (X) Legislative (Federal)

2. Description of Action: Involves solutions for meeting future water supply requirements for Eastern Massachusetts and explores various alternative ways to meet the projected needs for this region. Proposals include diversion during high flow periods from the Connecticut River via the Northfield Mountain pumped-storage facility directly to Quabbin Reservoir and by three other alternative methods to utilize and transport water from the Millers River Basin to the Quabbin Reservoir.

3. a. Environmental Impacts: Implementation would assure availability of projected water requirements for Eastern Massachusetts. Provides means to keep water quality high in Quabbin Reservoir by slowing down present depletion rate. An increased nutrient level in Quabbin Reservoir is expected. Depending on the alternate chosen, certain lands and waters will be dedicated to water supply in the Millers River Basin. Millers River water quality will be improved under two alternatives. May create a shift in present fishing patterns in Quabbin Reservoir. High diversion rates would cause appreciable loss of flow in the mainstem Millers River during portions of the diversion period.

b. Adverse Environmental Impacts: May include a temperature rise below the diversion point on the Millers River as well as a probable lessening of the sediment load and a partial loss of flushing action in the stream. No adverse effects are predicted for the mainstem of the Connecticut River or its estuary. No significant changes are predicted for Quabbin Reservoir. Some biota will become entrapped or entrained by the Northfield pumped-storage project.

4. Alternatives:

a. No Action
b. Weather Modification
c. Desalinization
d. Importation
e. Wastewater Reuse
f. Ground Water Resources
g. Dual Water Supply Systems
h. Other Diversion Sites
i. Water Demand Control
j. Re-examination of Release Schedules
k. Local Resource Potential
l. Population Zoning and Regulations

5. Comments requested (See attached sheets)

6. Draft statement sent to CEQ ____________.
Final statement sent to CEQ ____________.

5. Comments Requested (247)

Federal

First Coast Guard District
Federal Aviation Administration
Department of the Interior
Soil Conservation Service
Environmental Protection Agency
Federal Highway Administration
Bureau of Sport Fisheries & Wildlife
Department of Commerce
National Marine Fisheries Service
Office of Economic Opportunity
Federal Power Commission
New England River Basins Commission
U.S. Geological Survey
Department of Health, Education and Welfare
Department of Housing and Urban Development
National Park Service
Bureau of Outdoor Recreation
U.S. Department of Transportation
North Atlantic Division, Corps of Engineers

State

Conn. Water Resources Comm.
Conn. Office of State Planning
Conn. Board of Fisheries and Game
Conn. Department of Environmental Protection
Conn. Department of Community Affairs
Conn. Department of Public Health
Conn. Shell Fish Commission
Conn. Department of Agriculture
Conn. Institute for Water Resources
Hartford Metropolitan District Comm.
Mass. Office of Planning and Programming Coordination
Mass. Department of Public Works
Mass. Department of Natural Resources
Mass. Department of Water Resources
Mass. Division of Fisheries & Game
Mass. Department of Public Health
Mass. Agricultural Experiment Station
Mass. State Geologist
Mass. Water Resources Research Center
Mass. State Research Director
Mass. Department of Commerce and Development
Mass. Department of Community Affairs
Boston Metropolitan District Comm.

State (Cont'd)

N.H. Water Supply and Pollution Control Comm.
N.H. Water Resources Board
N.H. Fish & Game Department
N.H. Water Resources Research Center
N.H. Office of State Planning
Office of the Governor of N.H.
N.H. Natural Resource Council
N.H. Department of Public Health
R.I. Water Resource Center
R.I. Department of Natural Resources
R.I. Department of Health
R.I. Statewide Planning Program
R.I. Water Resources Board
Vt. Resource Research Center
Vt. Department of Water Resources
Vt. Planning and Community Services Agency
Tri-State Transportation Comm.
Southern N.H. Planning Comm.
R.I. State Comp. Trans. & Land Use Planning Program
Connecticut Regional Planning Agencies

- Capital
- Central
- Southeastern
- Conn. River Estuary
- Litchfield Hills
- Midstate
- Northeastern
- Windham
- Greater Bridgeport
- Central Naugatuck Valley
- Southwestern
- Valley
- South Central
- Conn. Interregional Planning Program

Massachusetts Regional Planning Agencies

- Metropolitan Area
- Old Colony
- Southeastern
- Montachusetts
- Central Merrimack Valley
- Northern Middlesex Area
- Berkshire
- Lower Pioneer Valley
- Central Massachusetts
- Cape Cod
- Dukes County
- Franklin County

Private Organizations

Portland Water District
Connecticut Water Company
Massachusetts Audubon Society
Anderson-Nichols, Inc.
Union of Concerned Scientists, MIT
New England Natural Resources Center
League of Woman Voters, Mass.
League of Woman Voters, Conn.
Charles River Valley Group of the L.W.V.
Curran Associates, Inc.
Normandeau Associates, Inc.
The Maine Assoc. of Conservation Comm.
WCAT-Berkshire Broadcasting
Orange Enterprise & Journal
Orange Board of Health
Abt Associates, Inc.
Essex Marine Laboratory, Inc.
Associated Industries of Mass.
New England Water Works Assoc.
American Water Works Assoc., Inc.
Salem and Beverly Water Supply Board
Westfield River Watershed Assoc.
Trout Unlimited
Millers River Watershed Council
Fenton G. Keyes Assoc.
Broadmoor Sanctuary
Nashua River Program
Massachusetts Wildlife Federation
Worcester Telegram and Gazette
The Outdoor Message
National Wildlife Federation
Appalachian Mountain Club
Water Department, Cambridge
Ipswich River Watershed District Comm.
Conn. River Valley Flood Control Comm.
Merrimack River Valley Flood Control Comm.
Thames River Valley Flood Control Comm.
Conn. River Watershed Council, Inc.
Parker River Watershed Council
Farmington River Watershed Assoc.
Housatonic River Watershed Assoc.
Canoe River Watershed
Mystic River Watershed Assoc.
North and South Rivers Watershed Assoc.
Ad Hoc Committee
Blackstone Valley Watershed Assoc.
Charles River Watershed Assoc.
League of Woman Voters of R.I.
League of Woman Voters of N.H.
League of Woman Voters of Vt.

Private Organizations (Cont'd)

Conn. Assoc. of Conservation Comm., Inc.
Conn. Audubon Council
Conn. Forest and Park Assoc., Inc.
The Nature Conservancy, N.H.
Council of Sportsmen's Clubs of Mass., Inc.
Mass. Assoc. of Conservation Districts
Mass. Forest and Park Assoc.
The Trustees of Reservations
Federated Sportsmen's Clubs of N.H., Inc.
Audubon Society of N.H.
Land Use Foundation of N.H.
N.H. Assoc. of Soil Conservation Districts
N.H. Natural Resources Council, Inc.
Seacoast Anti-Pollution League, N.H.
Society for the Protection of N.H. Forests
Statewide Program of Action to Conserve Our Environment, N.H.
Audubon Society of R.I.
Environmental Council of R.I., Inc.
R.I. Assoc. of Soil and Water Conservation District Supervisors
Vermont Natural Resouces Council
Merck Forest Foundation, Inc.
The Nature Conservancy, Vt.
Vermont Assoc. of Conservation Districts
Environmental Protection Comm., Conn.
N.E. Research, Inc.
Mass. Water Works Assoc.
New England Natural Resources Center
Worcester County League of Sportsmen
Merrimack Valley Region Assoc.
Agency of Environmental Conservation, Vt.
Conn. River Estuary R.P.A.
Ipswich River Water District
Neponset Conservation Assoc.
Westport River Improvement Assoc.
Essex County Greenbelt Assoc.
Tenmile River Task Force
Lake Cochituate Watershed Assoc.
Reading Greenbelt Assoc.
Orange Conservation Comm.
Civil Engineering Dept. , Univ. of Conn.
Marine Resources Committee
Coastal Research Center , Univ. of Mass.
National Foundation For Environmental Control
Sierra Club
Environment Inform. Ctr, Inc.
New York Times
Greater Boston Ecology Action Ctr.
Metropolitan Area Plng. Council
Nashua River Watershed Assoc.
Mass. Port Authority

Private Organizations (Cont'd)

Conn. Wildlife Federation, Inc.
Save The Wetlands Committee, Ct.
Conn. Action Now, Inc.
Conn. Audubon Society
Conn. Assoc. of Soil and Water
Conservation Districts, Inc.
N.H. Water Works Assoc.
Environmental Conservation
Middlesex Conservation District

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INTRODUCTION

The 89th Congress recognized that the assurance of adequate supplies of water for the great metropolitan centers had become a problem of such magnitude that the welfare and prosperity of the United States required the Federal Government to assist in its resolution. Consequently, the Congress enacted the Northeastern United States Water Supply (NEWS) Study on 27 October 1965, under Title I of Public Law 89-298.

A copy of the law, with a map of the study area on its reverse side, is attached. It authorized the Secretary of the Army, acting through the Chief of Engineers, to prepare plans to meet the long range water supply needs of the Northeast, in cooperation with Federal, State and local agencies. The Chief of Engineers, in turn, assigned responsibility for the NEWS Study to the Division Engineer, North Atlantic.

The NEWS Study area includes those river basins within the United States which drain into Chesapeake Bay, into the Atlantic Ocean north of Chesapeake Bay, into the St. Lawrence River, and into Lake Ontario. The study area, therefore, includes all of Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New Jersey, Delaware, and the District of Columbia, and parts of New York, Pennsylvania, Maryland, Virginia, and West Virginia.

An area of approximately 200,000 square miles, the area contains a population of about 50 million persons which is projected to reach about 85 million by the year 2020. Some 60 percent of the present population is concentrated in the five metropolitan areas of Boston, New York, Philadelphia, Baltimore and Washington. It includes twenty of the nation's one hundred largest cities. The municipal water suppliers of the region serve populations varying from less than 100 to 8.5 million. Although the area has an average annual precipitation rate of about 40 inches, as compared to the national average of 30 inches, precipitation deficiencies in some parts of the area were up to 50 inches during the October '61 to December '65 period. The area's vulnerability to water shortage is revealed by the fact that some 14 million people, about 28 percent of the population, were restricted to some degree in their use of water during this drought. Although public awareness of the problems of water supply is increased by drought experiences, drought is not the only reason for concern. Available supplies of water of good quality will soon be inadequate, even under normal conditions, to meet the needs of the expanding population and industrial growth.

The objective of the NEWS Study is the preparation of a coordinated general plan for essential water supply development in the Northeast which will recommend to the Congress an active program for Federal, State, local, and private organizations. Such plans shall provide for appropriate financial participation by the States, political subdivisions thereof, and other local interests. It will thus provide a public forum where all vitally concerned with the water supply problems of the area can be heard in developing a plan to resolve one of the domestic problems now facing the United States.

In achieving its objective, the NEWS Study is presenting a regional assessment of present and future water supply needs and will explore alternatives for their solution. The study effort is being fully coordinated through the various Federal, State, local and private agencies and organizations. This coordination will assure that plans are consistent with, and integral to, other concurrent water resource planned development being formulated. Thus, the NEWS Study can provide a framework through which all elements may effectively work together toward securing adequate water supplies. During the study, interim reports will be prepared to deal with critical problems which may be encountered. These reports will contain specific recommendations to the Congress for authorization of major reservoirs, conveyance facilities, or treatment facilities, as may be appropriate. The Northfield Mountain Diversion and Diversion from the Millers River Basin are the studies which are the subject of this preliminary draft Environmental Statement.

The NEWS Study effort was organized and initiated during the last half of 1966 with the preparation of a plan of study and the acquisition of data and reports. There followed a series of initial public hearings; the development of statistical information on public and private water supplies; a summary of drought information, including restrictions and shortages experienced in various communities; an appraisal of the degree of urgency for additional water supply in various regions of the study area; an analysis of the water supply potential of one selected area by the use of advanced statistical hydrologic techniques; and the initiation of studies in specific urgent regional metropolitan areas.

The NEWS Study has established the premise that areas in which the projected demand for water supply in 1980 will probably exceed the present capabilities of the systems will be considered in the "urgent" category. Under NEWS procedures, projects and regional programs for these urgent areas will be developed and made the subject of interim reports which will be submitted to the Congress for authorization. To identify these urgent areas, an initial appraisal was made of the present systems to satisfy the projected 1980 demands. This appraisal included an evaluation of present system capabilities, present and projected domestic and industrial consumption, population expansion and economic growth. The appraisal disclosed four critically urgent areas as follows:

1. Eastern Massachusetts and Rhode Island
2. Western Connecticut - Metropolitan New York City and Northern New Jersey
3. South Central Pennsylvania, Baltimore
4. Metropolitan Washington, D. C.

Once these critical areas had been identified, feasibility detail studies were initiated to investigate alternative engineering solutions. The western Connecticut area, although in the New England Division, because of its geographic proximity to the Metropolitan New York area was studied in conjunction with that region. The second "urgent" need area within New England, i. e. Eastern Massachusetts, was studied by members of the New England Division.

The Division Engineer, New England Division, cooperated in the NEWS Study by preparing an engineering feasibility study for this area. Aimed primarily at the water short areas of eastern Massachusetts, this study included Rhode Island, since evaluation of a potential regional scheme could involve consideration for the future needs of that state. The study, initiated in December 1968, was performed in consultation with representatives of the States of Massachusetts, Connecticut, Rhode Island, and of the New England River Basins Commission. A report of the study results, the engineering alternatives feasible for the area, was prepared and submitted for review and comment in draft form in November 1969. Following a review period and receipt of the review comments, a meeting was held in May 1970 with representatives of the Federal, State, and local agencies and interests to reach agreement on the best future course for the NEWS Study to pursue in continuing studies in the area.

It was agreed that the Corps proceed with detailed studies on the development of Tully Reservoir; initiate detailed studies on the Northfield Mountain development to complement studies by the Metropolitan District Commission; initiate studies on the requirements for improving the water quality of the Merrimack River together with a detailed investigation of the use of the River as a possible water supply source for the Eastern Massachusetts area; conduct a broad environmental impact study of water supply alternatives; perform detailed studies of the effect of upstream diversion on the estuaries of the Merrimack and Connecticut Rivers; and explore the possibilities of advance site acquisition in Rhode Island.

In addition to the progress meetings, held during the course of the study, four informal information meetings were held within the Millers River Basin. These meetings were held In Athol, Massachusetts on 21 October 1971 and 4 January 1972, in Winchendon, Massachusetts on 2 March 1972, and in Athol, Massachusetts on 8 May 1972.

During December 1971 and January 1972, a series of four formulation stage public meetings were held in Needham, Woburn, Orange, and Longmeadow, Massachusetts. These meetings were designed to broaden public participation in the open planning process by describing the on-going studies and receiving audience input. Some people spoke in favor of the plans presented. Others thought that we should concentrate on reducing demand instead of diverting more water to Eastern Massachusetts. A number of people at the Orange meeting suggested that water be diverted from the Millers River itself after pollution abatement. These ideas and others expressed at the public meetings were investigated as part of our studies and considered in the formulation of all plans. Late Stage Public Meetings were held in Waltham and Orange, Massachusetts on July 5 and 6, 1972.

ENVIRONMENTAL IMPACT STATEMENT BACKGROUND INFORMATION

This statement consists of an assessment of the environmental resources affected by the Millers and Connecticut River diversions, an analysis of the probable environmental impacts of each plan, and possible alternatives. The study of the Merrimack River Diversion will be the subject of a separate action.

The following pages describe the efforts of an integrated multi-discipline team of both Corps of Engineer personnel and services from two environmental consulting firms. This preliminary draft statement is meant to examine the potential trade-offs presented by the proposed water diversions.

A considerable portion of the available time and effort was devoted during the course of the study to the ecological, environmental, and public health aspects of the various proposals. Pages 56 to 105 located in Section 3 of this statement contain specific detailed information and descriptions of the various analysis used by the two environmental consulting firms during the course of the study. Although their complete reports are not included as part of this statement, care has been taken to include all their principal findings and conclusions for the benefit of the reviewer.

The information contained herein reflects a preliminary assessment of the physical and biological characteristics of each donor and receiver system and the potentially affected resources based on existing knowledge. Some specific details on the probable effect identified for each proposal are still unknown. In addition to public review of each proposed diversion project, a thorough analysis will also be completed by various Federal, State, and local agencies.

The preliminary assessment, which was prepared for the Late Stage Public Meetings, together with detailed environmental data compiled by contracted consulting firms, and information and comments gained at the public meetings, provided the basis for this preliminary draft Environmental Impact Statement for the proposed diversion projects. This preliminary draft will be coordinated with all known interests. A 45 day review period will be provided for public and private review. After comments are received, this preliminary draft will be rewritten with consideration given to pertinent views expressed during the coordination period. All correspondence received will be attached to the final version of the preliminary draft statement.

1. Project Description. Possible water supply diversion proposals under consideration for the purpose of providing water to the Boston Metropolitan District area are: (a) diversion of Merrimack River water directly into the Metropolitan District Commission's system, (b) diversion of Connecticut River water through the Northfield Mountain pumped storage power project into Quabbin Reservoir, and (c) diverting water from the Millers River Watershed into Quabbin Reservoir utilizing three alternatives, namely: (1) Millers River Diversion - taking water directly from the Millers River, (2) Tully - Millers River Diversion - taking water directly from the East Branch Tully River in addition to the Millers River, and (3) Tully Complex Diversion - taking water from Tarbell Brook, Priest Brook, Tully Reservoir and West Branch Tully River. No known National Register properties would be affected by the projects.

NORTHFIELD MOUNTAIN DIVERSION PROJECT

Authorization for construction of the diversion facilities from Northfield Mountain to Quabbin Reservoir has been granted to the Metropolitan District Commission by the Massachusetts State legislature. Recognizing this fact, the representatives of the Federal, State and local agencies and interests at the May 1970 meeting recommended that the Corps of Engineers investigate the project as a very viable element in any regional water supply plan for Southeastern New England. It was further recommended that the NEWS studies be designed to complement those under way, or planned by the Metropolitan District Commission.

The Northfield Mountain Diversion project as in the Millers River Basin Alternatives would use a high flow skimming technique; that is, flow would be diverted during high flow periods, principally during spring run-off periods. As a means of control, diversions would not occur if flow in the Connecticut River at Montague City U. S. Geological Survey gaging station is less than 17,000 cubic feet per second or about 11,000 million gallons per day. This control flow is specified in the current Massachusetts State Legislation regarding the Northfield Mountain project.

<u>Description of the Facilities</u>

In this project, water would be diverted from the Connecticut River through the Northfield Mountain pumped storage hydroelectric facility located in Northfield and Erving, Massachusetts.

The pumped storage project for electricity generation consists of a high level storage reservoir on Northfield Mountain, underground pump-turbine facilities and low level storage in the Turners Falls pool. The high level reservoir consists of a system of dams and spillways to provide 17,000 acre-feet of storage about 800 feet above the Turners Falls pool on the Connecticut River.

In order to provide the water supply diversion volume, the electric utility would pump an additional 375 million gallons each day that control flows in the Connecticut River would allow. The additional yield which could be made available by this plan would be 84 million gallons per day on a long term average annual basis. Because of operational considerations, however, the yield estimated to be made available to Quabbin Reservoir is about 72 million gallons per day.

In order to incorporate the water supply diversion into the Northfield Mountain Project, three modifications to the pumped storage facilities are necessary. These are:

1) Raising the upper reservoir located on Northfield Mountain about 4 feet to provide about 50,000,000 cubic feet of additional storage capacity.

2) Provision of head works at the upper reservoir for the diversion aqueduct to Quabbin Reservoir.

3) About 9.8 miles of connecting aqueduct and outlet facilities at Quabbin Reservoir.

The first two items necessary for diversion have been essentially completely constructed at the upper reservoir on Northfield Mountain by the electric utility construction forces. A plan of these facilities is shown in the attachment.

The third item necessary for water supply diversion is presently in preliminary design stages by engineers at the MDC. At present, plans indicate water would be diverted from the upper reservoir through an eight foot diameter steel pipe constructed in the east dike of the Northfield Mountain upper reservoir. Water would be withdrawn at an average rate of 375 million gallons per day and delivered to an intake shaft of the Northfield-Quabbin tunnel aqueduct.

The intake down shaft would be a scroll type configuration with a diameter of 16 to 18 feet. Water would be conveyed from a maximum upper reservoir pool elevation of 1004 feet msl in this vertical shaft to the aqueduct at elevation 300 feet msl.

The aqueduct would be a 10 foot finished diameter tunnel with a reinforced concrete liner. From the downtake shaft, the aqueduct would run about 0.5 miles to the vicinity of the south bank of the Millers River. At the Millers, a 10 foot diameter construction shaft would be excavated.

Continuing to Quabbin, the aqueduct would be driven about 3.0 miles to the vicinity of Bullard Hill. In this tunnel reach, the aqueduct would rise from the 300' elevation at the Millers River to elevation 440'. A second construction shaft would be provided at this location.

From Shaft No. 3, the tunnel would continue about 6.2 miles to the uptake shaft located in Rattlesnake Hill adjacent to Quabbin Reservoir. At Rattlesnake Hill, an uptake shaft would be driven from elevation 440 to elevation 500. At elevation 500, the tunnel would be enlarged from ten to 30 feet in width in a 150 foot long transition zone. Flow entering Quabbin from the transition zone would be conveyed in a 30 foot wide channel cut to the main channel of the Middle Branch of the Swift River.

Cost estimates for the water supply element of the project, including the raising of the upper reservoir, intake works, connecting tunnel aqueduct to Quabbin Reservoir and outlet works, would total about 40 million dollars.

Preliminary estimates of land needed for this project total about 30 acres. Land requirements for this plan may also involve about 5 acres for rock excavated from the tunnel. The firm requirement for these lands, however, would be determined during detailed design.

A major element considered in the evaluation of this project was the impact which the diversion could have on the environmental health of Quabbin Reservoir. A description of these possible impacts is included in Section 3.

MILLERS RIVER BASIN ALTERNATIVES

Three alternatives were developed to meet the water demands of the expanded regional system. Plates of these three alternatives are included at the end of this section as well as an estimated demand chart. The first is diversion directly from the Millers River above Athol to Quabbin Reservoir. This diversion would result in an average annual yield of 68 mgd and would require advanced treatment of the point sources of pollution on the Millers River, upstream of the diversion site. The second alternative is a combination of one and three. Water would be diverted only from the East Branch Tully River and from the Millers River above Athol, resulting in an average annual yield of 76 mgd. As in the first alternative, advance waste treatment of the pollution sources would be required; but because Tully Lake would not be used for water supply storage, the reservoir would not have to be stripped. Alternative three is the Tully Complex - a series of small diversion works on four tributaries of the Millers River. An average annual yield of 48 mgd is expected with no treatment required before entering Quabbin Reservoir.

Alternative No. 1 - Millers River Diversion

The potential of diverting water from the Millers River to Quabbin Reservoir was recognized even prior to the construction of the reservoir. Thus when the reservoir was designed and constructed in the 1920's and 1930's, the storage capacity was intentionally developed larger than the natural drainage area might require. With this historic precedence, diversion from the mainstem Millers River, therefore, was one of the alternatives investigated in the NEWS Study. In this alternative, water would be diverted from the mainstem Millers River above Athol, Mass. An inlet structure on the Millers River, a 10-foot diameter tunnel to Quabbin Reservoir and an outlet structure within the reservoir area would be required. At present, proposed pollution abatement plans by Massachusetts State Agencies include secondary treatment on all point sources of pollution on the Millers and Otter Rivers. However, investigations indicate that additional treatment appears necessary to insure a good water supply source and have been included as elements in this alternative.

The diversion site would be located on the Millers River about three miles upstream from the confluence of the Tully and Millers Rivers in Athol, Massachusetts. The structure located in Athol would consist of an inlet to the 10 foot diameter tunnel to Quabbin Reservoir controlled by a combination weir-bascule gate extending across the Millers River. The concrete control structure, 120 feet long, would provide a regulated pool for the inlet shaft. The bascule gate, 70 feet long and 5 feet high, would regulate the water height and velocity to the inlet. During diversion, the bascule gate would be raised creating a stilling pond and increasing the water level above the elevation of the inlet structure weir. The 22 foot diameter morning glory inlet tapering to the 10 foot diameter inlet shaft would be located on the northern bank in the center of a 60 foot square chamber cut in rock. The three 8 x 8 foot gates to the inlet chamber would be opened only when diversions were occurring. By regulating these gates in conjunction with the bascule gates, any combination of diversion flows and downstream flows can be achieved.

Water diverted from the river would enter the morning glory inlet and drop down the 10 foot diameter vertical shaft into the tunnel. The 10 foot diameter tunnel would run a distance of 7 miles from the the Millers River inlet to a point south of Gays Hill on Quabbin Reservoir. The tunnel would be excavated in rock by mole methods and lined with concrete to a finish diameter of ten feet. Both the inlet and outlet shafts would be used as construction shafts. The outlet at Quabbin Reservoir would consist of an inclosed transition structure, a concrete stilling basin and a 20 foot wide trapazoidal channel leading to the Middle Branch of the Swift River in Quabbin Reservoir. The structure would be founded on bedrock and includes a wet well with two 8 x 8 foot gated passageways and a control building. The stilling basin would reduce velocities to a reasonable level if Quabbin Reservoir was below elevation 503 msl; but if the pool was higher, discharge would be directly into the pool. The riprapped channel would extend from the stilling basin some 800 feet across a swampy area to the original Middle Branch of the Swift River channel. This channel makes its way to Windsor Dam and the Quabbin-Wachusett tunnel inlet.

At present, the Millers River mainstem is highly polluted. There are six major sources of pollution upstream from Athol, which include four municipal and two industrial sources. The Otter River receives wastes from Gardner, Baldwinville, Seaman Paper Company and Baldwinville Products Company; and the Millers River, from Winchendon and South Royalston. The remainder of the watershed is basically forested with individual homes, small farms and an occasional small business. The major sources of pollution in the basin above Athol are the two paper mills located on the Otter River. All of these pollution sources cause the Otter River and the Millers River from its confluence with the Otter River to be of unsatisfactory quality.

As it exists at present, then, diversions for water supply purposes cannot be considered because of water quality problems. A report prepared by the Metropolitan District Commission for the Massachusetts State Senate in 1967 bears out this conclusion. In that report, it was noted that the Millers River mainstem would require "elimination of sewage and manufacturing wastes before consideration could be given to these sources for water supply purposes."

The NEWS Study, however, cognizant of the Massachusetts and Federal Pollution Abatement schedule, next attempted to forecast the effect of pollution abatement on its plans. Based on our evaluation, it appeared that the river, even after proposed secondary treatment "clean up," might require additional or advanced waste treatment at the point sources of pollution. This additional treatment, over and above that presently planned, is thought necessary to insure good quality water which would not be injurious to either public health or to the environmental quality of Quabbin Reservoir.

Additional yield which could be made available by this alternative would be about 68 million gallons per day on an average annual basis.

A number of questions still remain, however, on the water quality of the Millers River even after "clean up." First, will existing sludge deposit within the river be a factor in the river water quality when the river is to be tapped as a supply source? Limited data indicates this sludge may contain trace metals such as mercury and cadmium, which are injurious to health. Second, what influence would non-point sources of pollution, e.g., old abandoned dumps, urban run-off, etc., have on the water quality? Third, advanced waste treatment applications are limited. Although experience to date has been favorable, can it be said with certainty that plants would be performing to full expectation at the time diversions were needed?

Answers to all of these questions are, of course, difficult without the benefit of actually observing the river's natural reaction to "clean up." If, for example, this alternative were chosen and work undertaken, there is a possibility that the river may still not be suitable for diversion to Quabbin. If this, then, were the case, the needed supply would not be available for communities in need.

In an attempt to answer whether in fact it could be guaranteed that the river would be suitable for diversion as a water supply source when needed, both State and Federal Public Health authorities were consulted. In correspondence directed to the Massachusetts Department of Public Health, the question was asked, "Would the responsible State Agencies, including the Public Health Department, agree that diversions from the Millers River itself could be accomplished without actual observation of the river's natural reaction to pollution abatement and resulting water quality." The response to this question in part read, "Plans and proposals for the eventual construction of municipal and industrial waste treatment plants, degree of treatment, effectiveness of treatment and operational problems are all areas subject to so many variables that the Department is unwilling to speculate on the hypothetical premise of the suitability of this supply under any given set of conditions."

Apparently, then, if this alternative were chosen, no guarantee can be given that water when needed would be available. This "risk" then was also considered in the evaluation of this and the other alternatives.

The question still remains, however, and will remain until the actual "cleaned up" river water can be tested and evaluated, as to the impact of diverted Millers River water on Quabbin.

If this alternative were implemented, however, the socio-economic impact on communities within the basin should be positive. The facilities to insure use of the river as a water supply source would provide an excellent quality water in the river. A clean Millers River would open up important new recreation and land use opportunities, not now enjoyed because of the polluted nature of the river. Quabbin Reservoir's environmental quality may be insured and the entire region would benefit by its continuing good quality.

In summary, then, clean up and diversion of Millers River water as a water supply source has many advantages from an economic, environmental and socio-economic viewpoint.

Disadvantages associated with this proposal are the unknown factors which may preclude use of the river when needed. These unknowns include both public health and environmental considerations relating to Quabbin Reservoir and consumers of the system's water. Also, if water were not available when needed, large socio-economic impacts could be anticipated in those cities and towns which rely upon the Quabbin - Wachusett - Sudbury Reservoir system.

Alternative No. 2 - Tully-Millers Diversion

In this plan, diversion from the Millers River Basin would be accomplished via withdrawals from the East Branch Tully River and the mainstem of the Millers River above Athol, Massachusetts. Facilities necessary for development would include a morning glory type inlet structure just downstream from the existing Tully flood control reservoir and an 8 foot diameter tunnel to the Millers River above Athol. At the Millers River, a second tunnel inlet would be constructed and from this location, a 10 foot tunnel would be driven to Quabbin Reservoir where water would be discharged through an outlet structure. As in Alternative No. 1, waste treatment plants on six point sources of pollution would also be required. Plate No.2 shows the location of the proposed structures.

One diversion site for this alternative is located at the existing Corps of Engineers flood control reservoir on the East Branch Tully River. However, no storage would be used for water supply within the flood control reservoir. The site is located about 4 miles upstream from the confluence of the Tully River and Millers River in Athol. The structure would consist of an inlet to the 8 foot diameter tunnel to the Millers River above Athol and an 8 foot high bascule gate attached to the existing Tully Lake outlet channel.

The existing outlet channel of Tully Lake would be enlarged to 30 feet wide for a distance of 1200 feet. A 30 foot long, eight foot high gate would regulate the water height and velocity in the outlet channel. During diversion, the bascule gate and the three 8 x 8 foot gates would be raised creating a stilling pool and increasing the water level above the lip of the tunnel inlet. The 22-foot morning glory drop inlet would be located adjacent to the outlet channel in the middle of a 60 foot square chamber cut in rock. The three 8 x 8 foot gates to the inlet chamber would be opened only when diversions were occurring. By regulating these four gates and the gates at the existing dam, any combination of diversion flows and downstream flows can be achieved.

Water entering the morning glory inlet would drop some 312 feet down the vertical eight-foot shaft into the tunnel. The eight-foot diameter tunnel would be driven a distance of 2.5 miles from the outlet of Tully Lake to a point upstream of Athol on the mainstem of the Millers River. The tunnel would be excavated by mole methods and concrete lined to a finish diameter of eight feet.

The Millers River diversion would be in the same location as Alternative No. 1. The facilities would include a weir-bascule structure across the river and a morning glory inlet to the tunnel. A ten-foot diameter tunnel would run from the Millers River intake to an outlet at Quabbin Reservoir. All these facilities would be similar to those required in Alternative No. 1.

An analysis was made on the present and projected waste loadings upstream of the diversion sites, on the present and planned treatment and on the present and planned waste effluents. Based on available information, it appears the East Branch Tully River water is of good quality requiring no treatment prior to discharge into Quabbin Reservoir. However, as in Alternative No. 1, further treatment of Millers River water is required.

The operation of this diversion would depend first on the flow in the Connecticut River as measured at the U.S.G.S. gaging station at Montague City, Massachusetts; and secondly, on the flow in the rivers at the two diversion sites. On any given day, the flow in the Connecticut River at Montague City would be checked to see if the flow is above 17,000 cfs. If it is not, then no diversion would occur no matter what the flow in the Millers or Tully Rivers is. If the flow in the Millers River at the diversion site is less than the flow determined to be required for the river and its environment, then no diversion from the Millers River would occur. This required flow, referred to as the control flow, was determined from flow requirements for assimilation of wastes, for fish and wildlife, and for riparian rights and is related to the time of year and the drainage area. The following table shows the control flows at the Millers River intake:

	Jan Feb Mar	Apr May Jun	Jul	Aug	Sep Oct Nov	Dec
CSM	0.5	1.25	2.0	1.0	0.75	0.5
CFS	100	250	400	200	150	100

If the Connecticut River flow is above 17,000 cfs and the Millers River flow is above the control flow for that day, then diversion from the Millers River would occur. In no case would water be diverted lowering the flow in the river below the control flow. But, neither would the flow be augmented when it was naturally below the control flow. So, the rate of diversion on any given day could vary from zero to the maximum capacity of the tunnel, 730 cfs.

The same procedure would apply for diversion of East Branch Tully River water, except the control flows and the maximum diversion rate would be less. The control flows at the East Branch Tully River intake are as follows:

	Jan Feb Mar	Apr May Jun	Jul	Aug	Sep Oct Nov	Dec
CSM	0.5	1.25	2.0	1.0	0.75	0.5
CFS	25	63	100	50	38	25

If the Connecticut River is above 17,000 cfs and the East Branch Tully flow is above the control flow for that given day, then diversion from the East Branch Tully River would occur. The rate of diversion on any given day could vary from near zero to 490 cfs, the maximum capacity of the tunnel.

The flow rates in the Connecticut, Millers and East Branch Tully Rivers would be automatically fed into the control centers at the Tully and Millers River intakes. Also, water quality readings would be constantly read from the monitoring station one-half mile upstream of the Millers River diversion site. This information would then be used to determine if the diversions would occur and if so, at what rates. Diversion might occur at both sites simultaneously or possibly only at one site depending on the river flows. The bascule gates and inlet gates at each diversion site would be regulated in such a manner as to divert the maximum total amount of water to Quabbin Reservoir. The entire operation would essentially be controlled from the Millers River intake.

The same investigations as in Alternative No. 1 were performed to determine the effects on the environment of Alternative No. 2. Essentially, the effects would be similar to those of Alternative No. 1 - Millers River Diversion. This is due to the fact that comparable percentages of water will be diverted from the same watershed. The only difference is that water would be diverted from the East Branch Tully River affecting some 3 miles of the East Branch and 1 mile of the Tully River.

The same summary of possible environmental impacts on the estuary holds for Alternative No. 2 as for Alternative No. 1. Essentially, the changes due to diversion should not be significant, thus having only minimal biological effects.

On the Connecticut and Millers Rivers, similar impacts are expected as outlined in Alternative No. 1 - Millers River Diversion. The only difference would be the reduction in flow and stage on the East Branch Tully River and on the Tully River. With these limited reductions on the East Branch Tully River and the Tully River, minimal impacts on the four miles of two rivers are foreseen. Groundwater levels and water temperatures should stay about the same. The other downstream impacts have been given in the discussion of Alternative No. 1.

As in Alternative No. 1, the impact of diverted Millers River water on Quabbin Reservoir is impossible to discuss, but in very general terms. However, the East Branch Tully River water is presently adequate to be diverted to Quabbin. It is of the same quality as the Ware River which has been diverted for 30 years with no noticeable long-term impacts. In fact, diversion of East Branch Tully River water may help to improve the quality of Quabbin after the Connecticut River diversion is imple -

mented. This hinges around the "treatment plant" capacity of the reservoir to handle some restoration of water quality. By adding better quality water, such as the East Branch, the total volume is increased probably improving this capacity and the water quality.

Multi-purpose applications of this alternative would be similar to the Millers River alternative. The Millers River would be returned to its previous excellent quality offering numerous recreation opportunities. Additional incidental flood control benefits would occur because higher discharges from Tully Dam would be possible, knowing that a maximum of 490 cfs would be diverted to Quabbin Reservoir. However, this would reduce the amount of water diverted from the Millers River because the maximum capacity of the 10 foot section of tunnel is 730 cfs. During times of potential flooding, coordination should be maintained between Tully and Birch Hill Dams and the two diversion sites to insure the proper operation for flood control. Still, the benefits for flood control protection attributable to this alternative are minimal.

The existing "Master Plan for Reservoir Development" of Tully Dam would remain essentially the same. The plan consists of the development of a day-use park area including swimming facilities, Doane Falls scenic area, an overnight camping area, a canoe and hiking reserve and a primitive picnic and hiking area. The only changes from the 1965 Master Plan would be the redesign of the sanitary facilities to meet the Massachusetts Department of Public Health standards for water supply streams. Also, no diversions from Tully would occur during the recreation season. This would insure the protection of Quabbin Reservoir. With these changes, the seasonal use of Tully Lake for recreation would be developed according to the Master Plan.

The Tully-Millers alternative offers the same recreation and water quality opportunities as the Millers River alternative, but also provides flood control protection on the East Branch Tully River. Some 30 miles of streams would become excellent quality, increasing the aesthetic value of the river and associated land.

On the East Branch Tully River, no further testing on a scheduled basis would be required. Samples would be taken on an intermittent basis (four or five times during the diversion period). If anything showed up in these samples, then a sanitary survey would be performed to isolate the problem.

On the Millers River, the monitoring and sampling programs would be the same as for the Millers River alternative. A monitoring station would be set up a mile upstream of the diversion site and samples would be taken on a year round basis, a half mile downstream of the confluence of the Otter River. This program will provide ample protection against pollution reaching Quabbin Reservoir, and provide a valuable index of the Millers River water quality. Similar sampling stations as in the Millers River alternative would be set up in Quabbin Reservoir.

Alternative No. 3 - Tully Complex Diversion

This water supply plan for diversions from the Millers River Basin involves the construction of an 8-foot diameter tunnel from Tully Lake to Quabbin Reservoir, a dam on Priest Brook, and diversion structures on Tarbell Brook and West Branch Tully River. Water would be diverted in a pressure conduit from Tarbell Brook to the proposed Priest Brook ponding area. Pumping facilities at the Priest Brook Dam convey this water together with Priest Brook water to Tully Lake. A gravity feed tunnel would then divert these two brook's water plus the East Branch Tully water out of the basin to Quabbin Reservoir. Water from the West Branch Tully could then be pumped into the tunnel near the confluence of the East and West Branches of the Tully River. Recreation and wildlife management programs are also included at these diversion sites.

The Tarbell Brook diversion site is located in Winchendon, Massachusetts, about one-half mile upstream of the confluence of Tarbell Brook with the Millers River. The structure consists of a 75 foot long weir and pumping station. A 28 acre pool with a maximum depth of nine feet would be formed by the weir with a top elevation of 840 msl. The inundated area would be cleared and grubbed to improve its appearance. Water would be drawn from the pool and pumped through a 42" diameter pressure conduit running beside Royalston Road to the Priest Brook ponding area. The pumps and pipeline would be designed to carry a maximum of 90 cfs.

The Priest Brook Dam is located on the Winchendon-Royalston town line, just south of Winchendon Road, some 2-3/4 miles from the confluence of Priest Brook with the Millers River. The pool at spillway crest would have a surface area of 400 acres and a maximum depth of 30 feet. The inundated area downstream of Royalston Road has to be stripped or covered with a gravel blanket to prevent degradation of the water. A weir located upstream of Royalston Road would form a 40 acre wildlife pool. Regulation of this pool would occur during the summer and fall to maintain a shallow depth of water (approximately 5 feet). The 45 foot high main dam buffers the river flow and as such the pool is intermittently filled and emptied inundating the permanent wildlife weir.

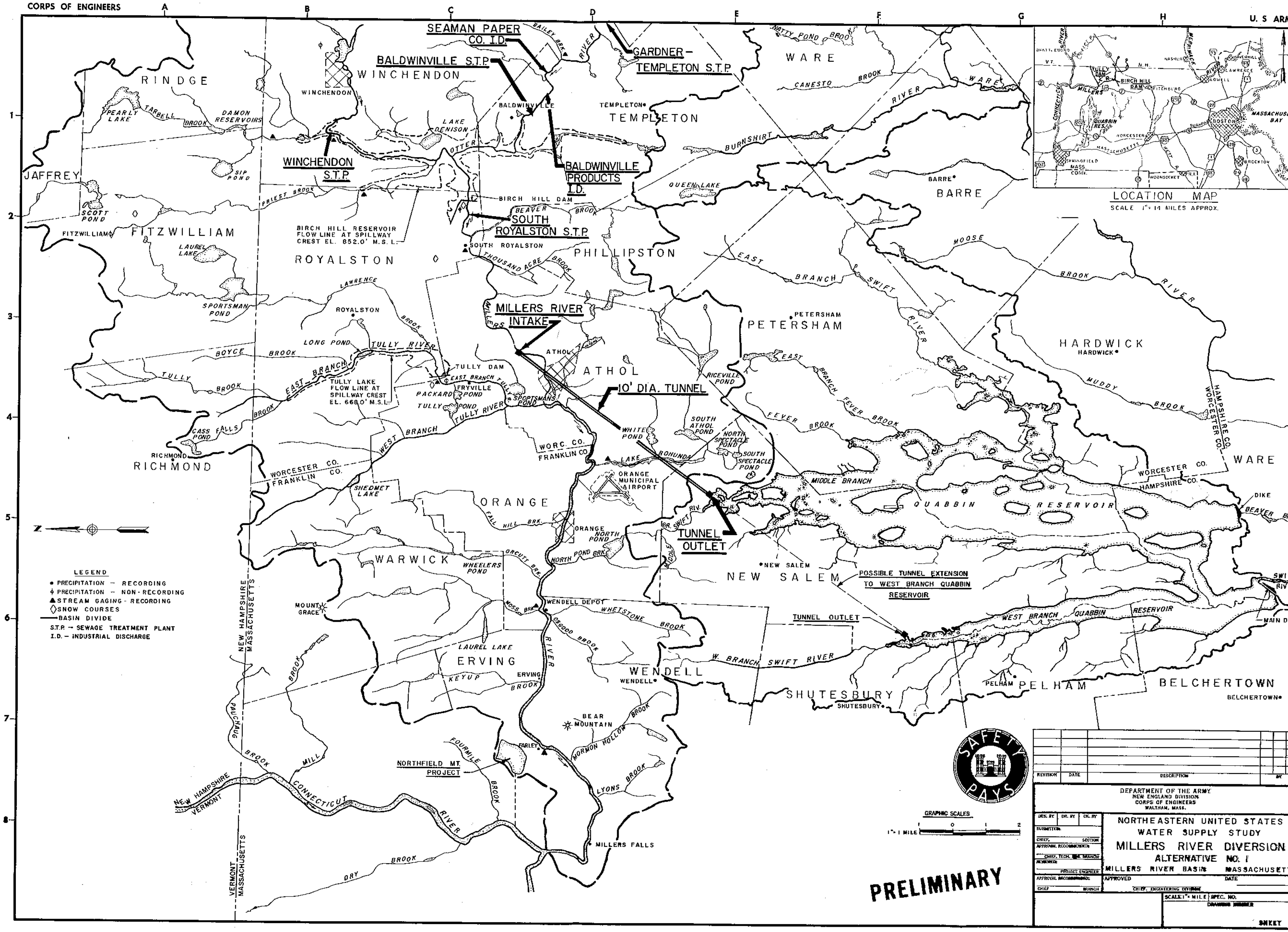
A pumping station located at the outlet would divert up to 120 cfs through a 72-inch pressure conduit to Tully Lake. The pressure conduit will run west beside Winchendon Road until it intersects a power line running northwest. Then the conduit follows this easement to Long Pond on the East Branch Tully River.

The diversion site on the East Branch Tully River is located at the outlet of the existing Corps of Engineers Tully Flood Control Reservoir. The existing outlet channel would be enlarged and a morning glory intake structure and a 7 foot high modified bascule gate added. Only two inches of the 8.3 inches of run-off storage in Tully would be utilized from 15 September to 15 June for re-regulating flows for diversion to Quabbin Reservoir. The remainder of the year, a recreation pool would be held at elevation 649 msl and no diversions from Tully would occur. In order to improve the water quality, the 620 acres inundated would be cleared, grubbed and stripped. Water diverted would enter the morning glory inlet and drop some 312 feet down the vertical eight-foot diameter shaft into the tunnel. The eight-foot diameter tunnel would run horizontally at elevation 300 msl for some 2.2 miles to the entrance shaft from the West Branch Tully River diversion.

The West Branch Tully River diversion site is located about 800 feet upstream of the confluence of the East and West Branch Tully River. The structure consists of a 320 foot long, 25 foot high earth filled dam with a 50 foot wide spillway, a water intake chamber and a pumping station. A permanent 13 acre pool would be formed by the dam to divert from and for wildlife habitat. A maximum of 90 cfs would be pumped from this pool to the intake shaft through a 30-inch diameter pressure conduit.

The water entering the eight-foot diameter tunnel would join with the flow from Tully Lake running in an 8.6 mile, eight foot diameter tunnel from the outlet of Tully Lake to a point south of Gay's Hill on Quabbin Reservoir. The tunnel would have a maximum capacity of 390 cfs.

The tunnel outlet would consist of an inclosed transition structure, a concrete stilling basin and a twenty foot wide trapezoidal channel leading to the Middle Branch of the Swift River in Quabbin Reservoir. The stilling basin would reduce velocities to a reasonable level if Quabbin Reservoir was below elevation 503 msl; but if the pool was higher, discharge would be directly into the pool.



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SOUTH ROYALSTON S.T.P.
BIRCH HILL DAM
BIRCH HILL RESERVOIR FLOW LINE AT SPILLWAY CREST EL. 852.0' M.S.L.
MILLERS RIVER INTAKE
10' DIA. TUNNEL
TULLY DAM
TULLY LAKE FLOW LINE AT SPILLWAY CREST EL. 668.0' M.S.L.
TUNNEL OUTLET
POSSIBLE TUNNEL EXTENSION TO WEST BRANCH QUABBIN RESERVOIR
NORTHFIELD MT. PROJECT
RINDGE
WINCHENDON
TEMPLETON
WARE
JAFFREY
BARRE
FITZWILLIAM
ROYALSTON
PHILLIPSTON
PETERSHAM
HARDWICK
ATHOL
RICHMOND
ORANGE
WARWICK
NEW SALEM
ERVING
WENDELL
SHUTESBURY
PELHAM
BELCHERTOWN
MILLERS FALLS
QUABBIN RESERVOIR
WEST BRANCH QUABBIN RESERVOIR
CONNECTICUT RIVER
NEW HAMPSHIRE
MASSACHUSETTS
VERMONT
LOCATION MAP
SCALE 1" = 14 MILES APPROX.
LEGEND
PRECIPITATION - RECORDING
PRECIPITATION - NON-RECORDING
STREAM GAGING - RECORDING
SNOW COURSES
BASIN DIVIDE
S.T.P. - SEWAGE TREATMENT PLANT
I.D. - INDUSTRIAL DISCHARGE
SAFETY PAYS
GRAPHIC SCALES
1" = 1 MILE
DEPARTMENT OF THE ARMY
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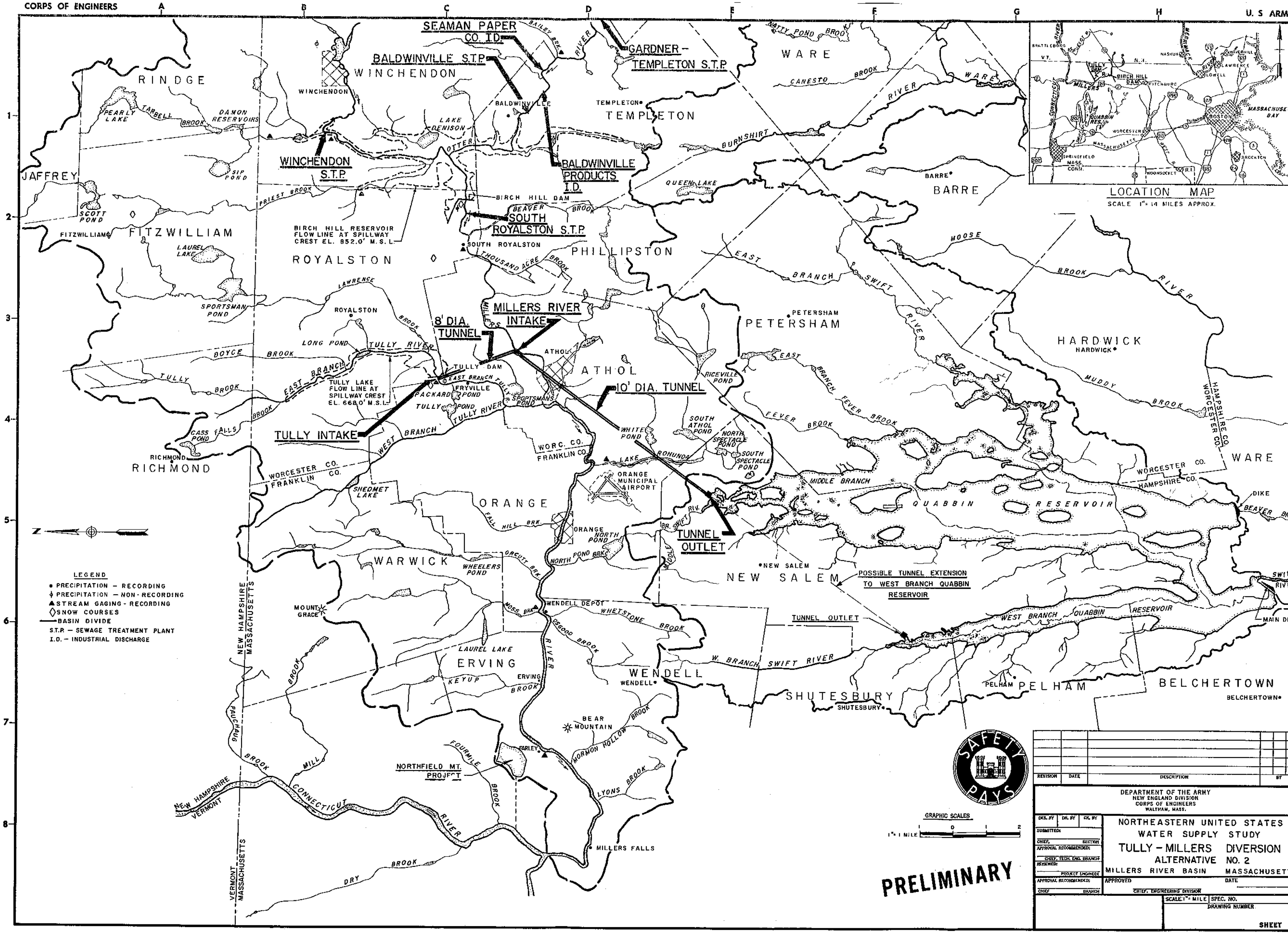
CORPS OF ENGINEERS
WALTHAM, MASS.
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
MILLERS RIVER DIVERSION
ALTERNATIVE NO. 1
MILLERS RIVER BASIN MASSACHUSETTS
PRELIMINARY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BALDWINVILLE PRODUCTS I.D.
WINCHENDON S.T.P.
SOUTH ROYALSTON S.T.P.
BIRCH HILL DAM
BIRCH HILL RESERVOIR FLOW LINE AT SPILLWAY CREST EL. 852.0' M.S.L.
MILLERS RIVER INTAKE
8' DIA. TUNNEL
10' DIA. TUNNEL
TULLY DAM
TULLY LAKE FLOW LINE AT SPILLWAY CREST EL. 668.0' M.S.L.
TULLY INTAKE
TUNNEL OUTLET
POSSIBLE TUNNEL EXTENSION TO WEST BRANCH QUABBIN RESERVOIR
NORTHFIELD MT. PROJECT
RINDGE
JAFFREY
WINCHENDON
TEMPLETON
WARE
BARRE
FITZWILLIAM
ROYALSTON
PHILLIPSTON
PETERSHAM
HARDWICK
ATHOL
RICHMOND
ORANGE
ORANGE MUNICIPAL AIRPORT
WARWICK
NEW SALEM
ERVING
WENDELL
SHUTESBURY
PELHAM
BELCHERTOWN
QUABBIN RESERVOIR
MIDDLE BRANCH
WEST BRANCH QUABBIN RESERVOIR
MILLERS FALLS
CONNECTICUT RIVER
WORCESTER CO.
FRANKLIN CO.
HAMPSHIRE CO.
NEW HAMPSHIRE
MASSACHUSETTS
VERMONT
LEGEND
PRECIPITATION - RECORDING
PRECIPITATION - NON-RECORDING
STREAM GAGING - RECORDING
SNOW COURSES
BASIN DIVIDE
S.T.P. - SEWAGE TREATMENT PLANT
I.D. - INDUSTRIAL DISCHARGE
LOCATION MAP
SCALE 1" = 14 MILES APPROX.
GRAPHIC SCALES
1" = 1 MILE
SAFETY PAYS
PRELIMINARY
DEPARTMENT OF THE ARMY
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CORPS OF ENGINEERS
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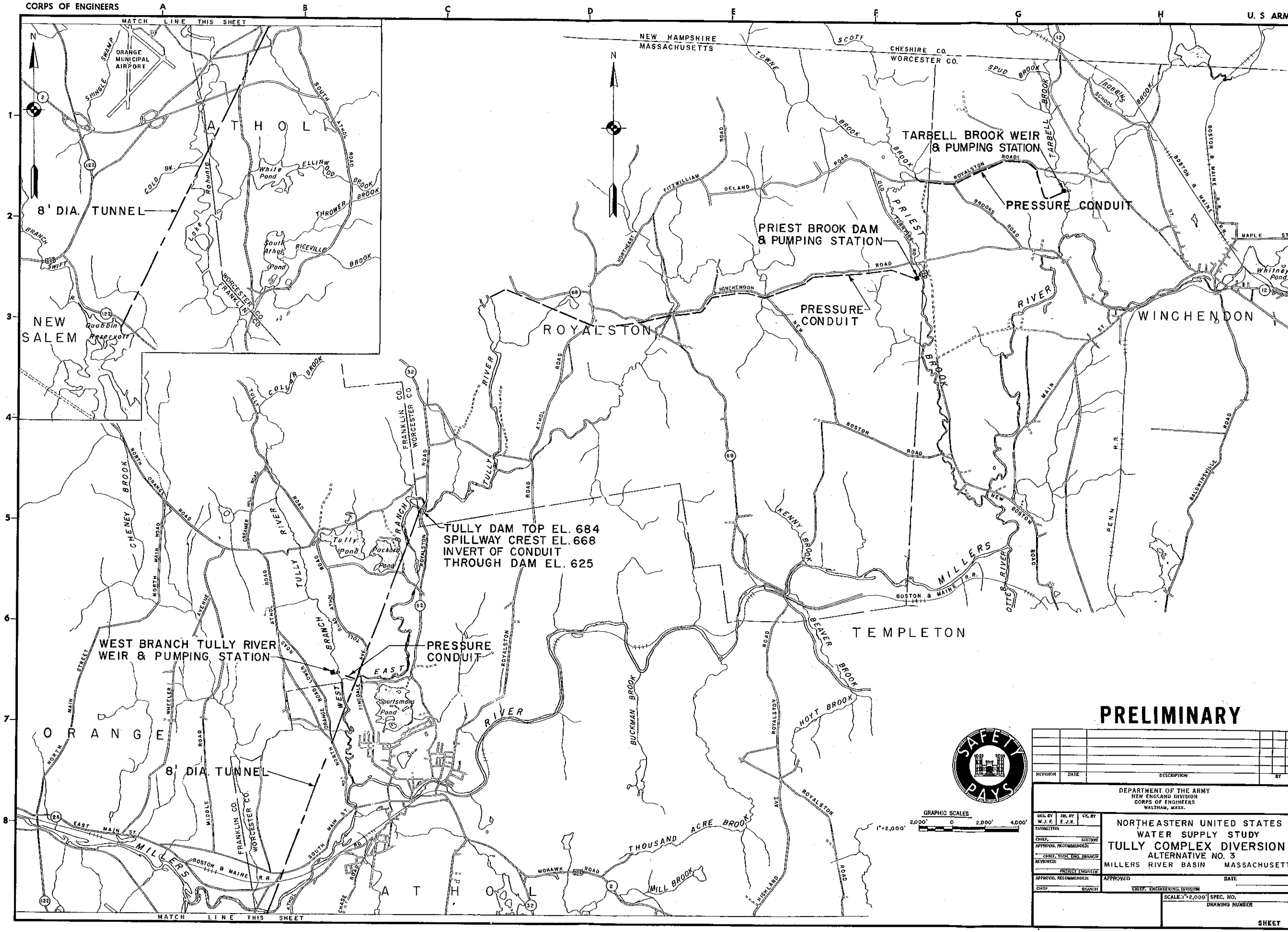
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
TULLY - MILLERS DIVERSION
ALTERNATIVE NO. 2
MILLERS RIVER BASIN MASSACHUSETTS
SCALE 1" = 1 MILE



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MATCH LINE THIS SHEET
ORANGE MUNICIPAL AIRPORT
ATHOL
NEW SALEM
Quabbin Reservoir
8' DIA. TUNNEL
NEW HAMPSHIRE
MASSACHUSETTS
CHESHIRE CO.
WORCESTER CO.
TARBELL BROOK WEIR & PUMPING STATION
PRESSURE CONDUIT
PRIEST BROOK DAM & PUMPING STATION
PRESSURE CONDUIT
ROYALSTON
WINCHENDON
TULLY DAM TOP EL. 684
SPILLWAY CREST EL. 668
INVERT OF CONDUIT THROUGH DAM EL. 625
WEST BRANCH TULLY RIVER WEIR & PUMPING STATION
PRESSURE CONDUIT
TEMPLETON
ORANGE
8' DIA. TUNNEL
ATHOL
MILLERS
THOUSAND ACRE BROOK
PRELIMINARY
SAFETY PAYS
GRAPHIC SCALES
1"=2,000'
REVISION DATE DESCRIPTION BY
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WALTHAM, MASS.
NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
TULLY COMPLEX DIVERSION
ALTERNATIVE NO. 3
MILLERS RIVER BASIN MASSACHUSETTS
APPROVED DATE
SCALE: 1"=2,000' SPEC. NO.
DRAWING NUMBER
SHEET

2. Environmental Setting Without the Project.

Northfield Mountain Diversion - Connecticut River Basin

The Connecticut River from its origin flows south for approximately 404 miles, the lower 60 of which are tidal, and drains an area of 11,265 square miles before emptying into Long Island Sound. The river flows through wilderness areas as well as highly populated urban communities such as Holyoke and Springfield, Massachusetts, and Hartford, Connecticut. Sixteen dams have been erected along the mainstem of the river, primarily to provide hydroelectric power.

The river supports industry, navigation, recreation, sport and commercial fisheries, as well as provides a domestic water supply to a number of communities in and outside the basin.

Historically, the Connecticut River has supported major runs of anadromous fishes including American shad, alewives, blueback herring, rainbow smelt, sturgeon, and Atlantic salmon. Though the first four of these species still complete their annual migrations for spawning within the lower reach, all were eliminated from the upper portion subsequent to dam construction. The Atlantic salmon has been entirely eliminated. A sport fishery does exist throughout the river's length; however, it reaches peak importance along the tributaries, largely through annual stockings of trout to maintain a "put-and-take" sport fishery. Efforts are being expended to restore anadromous fish to the entire watershed through construction of fish passage facilities at obstructions not having these and operation of salmon hatcheries. Pollution abatement programs to comply with State standards should lead to restoration of high quality aquatic resources and their utilization. The Environmental

Protection Agency's pollution abatement schedule for the Connecticut River sets 1976 as completion date for pollution control facilities.

The proposed diversion site at Northfield Mountain is located with a soon to be completed pumped storage hydroelectric facility. The pumps would be used during the non-generating period for the transfer of water from the Connecticut River via tunnel to Quabbin Reservoir during the spring run-off period. Anadromous fish species are not now found in this portion of the river, however, approximately 25 resident species have been collected within this reach. Three of these species are important sport fishes (walleye pike, bullhead, small-mouth bass).

Existing water quality is good to poor (B through D) depending upon location to population centers. The river receives both treated and untreated sewage as well as significant amounts of industrial waste.

Quabbin Reservoir

Quabbin Reservoir is the largest body of water in Massachusetts and the largest man-made impoundment in New England. It encompasses approximately 25,000 surface acres when full. Quabbin serves primarily as a domestic water supply source for 42 communities within the Metropolitan District Commission's jurisdiction. Public use of the impoundment is regulated by the MDC through controlled access and specific regulations. Quabbin has developed an excellent and popular sport fishery through the joint efforts of the MDC and the Massachusetts Division of Fisheries and Game. The more important species entering the sport fishery include: landlocked salmon, lake trout, small and large mouth bass, rock bass, pickerel, bluegill, pumpkinseed, brown bullhead, white and yellow perch, brown trout and rainbow trout. Some brook trout are taken in the tributaries.

Unpopulated State owned lands encompass more than 80,000 acres, most of which is covered by a dense coniferous forest. Although the project area contains an abundance of game animals, hunting is not allowed. Recreational use consists of regulated boating, fishing, sightseeing and hiking.

Millers River Basin

The Millers River rises in Ashburnham, Massachusetts and flows in a westerly direction for about 45 miles through Winchendon, Athol, and Orange to its confluence with the Connecticut River at Montague and Erving, Massachusetts. It has a drainage area of 392 square miles.

Principal tributaries of the Millers River are the Otter and Tully Rivers. There are two completed flood control dams in the Millers River Basin: Birch Hill Dam on the Millers River, and Tully Dam on the East Branch of the Tully River. The Millers River Basin is characterized by 78% forest cover, 11% open land, 8% wetland, and 3% urban area.

The main stem of the river contains both treated and untreated domestic sewerage and substantial amounts of industrial waste from several communities. The Otter River, one of the main tributaries to the Millers, is also heavily contaminated with sewerage and industrial waste, but for the most part, the small tributaries within the Millers Basin are relatively free of pollution.

Good trout habitat exists upstream of the confluence with the Otter River within the Birch Hill and Winchendon areas and this reach is stocked annually with rainbow trout by Massachusetts Division of Fish and Game. As a result of pollution in the Otter River and downstream reaches of the Millers River, a sport fishery is non-existent. Fish species consist primarily of suckers and bullhead. An occasional large mouth bass is taken well downstream near the confluence with the Connecticut River; however, the existence of this species is entirely dependent on water quality. White-water canoeing is a very popular recreational activity during the spring freshet season.

Alternative No. 1 Millers River Diversion

Alternate No. 1 proposes diversion directly from the Millers River above Athol to Quabbin Reservoir. From the city of Athol extending downstream to the Orange dam the setting is a wide level valley with the river meandering through an agricultural setting of pastures, meadows, and settled land. The stream bottom is mud and silt with extensive emergent vegetation as is the outlet of Lake Rohunta which joins the Millers River below Athol. The River is backed up by the Orange dam about a mile upstream. The zone between Orange and the Connecticut River is typified by steep banks, a sharp river gradient, long rapids followed by short pools, a complete absence of wetlands, and a boulder strewn rock rubble bottom. Some 22 species of fish are reported for the Millers River watershed. Population magnitude and locations are dependent on the particular species requirements as well as the man-made stress of pollution.

Alternative No. 2 Tully - Millers River Diversion

In this plan, diversion from the Millers River Basin would be accomplished via withdrawals from the East Branch Tully River and the mainstem of the Millers River above Athol, Massachusetts.

This alternate essentially results from the combining of Alternate No. 1 with the addition of a supplementary diversion from the East Branch of the Tully River to the diversion point on the Millers River discussed under Alternate No. 1. The environmental setting of the Millers mainstem was described in the foregoing section. The setting and resources of the East and West Branches of the Tully River are described in the following section with the exception of a short stretch of low gradient, wetland associated riverine habitat between the confluence of the two branches and the mainstem of the Millers River.

Alternative No. 3 Tully Complex Diversion

(1) Tarbell Brook Diversion

Tarbell Brook is a small, low gradient stream approximately $7\frac{1}{2}$ miles long from its headwaters to its confluence with the Millers River. Open water areas (which include lakes and ponds) along the stream cover $1\frac{1}{2}$ miles. The total drainage area is approximately 27 square miles of which about five are wetland, less than two are open water, and the remaining area representing upland habitat.

Flow is moderately rapid through forested areas and slow in open wetland areas. Stream width varies up to 30 feet. Depth is variable and measures several feet in some places. Water quality is good (class B). The adjacent habitat is primarily coniferous forest combined with mixed stands of hardwoods.

The stream is stocked annually with trout by the Massachusetts Division of Fisheries and Game which provides a "put-and-take" sport fishery. Several species of game such as woodcock, grouse, black duck, rabbit, squirrel, and deer inhabit the area.

During high water, Tarbell Brook is canoeable from the New Hampshire border to its confluence with the Millers River.

(2) Priest Brook Diversion

Priest Brook, including Scott Brook, (its main northern tributary) extends approximately 14 miles from its headwaters in southern New Hampshire to its confluence with the Millers River. Open water areas cover one mile along the stream which is of moderate to low gradient and flows through forested and wetland areas. Width varies up to 40 feet and depth is variable, generally three feet but as much as six in some areas.

The total drainage area is approximately 23 square miles of which about three are wetland, less than one is open water, and the remaining area is upland habitat. Water quality is good (class B) but below average for trout during summer months due to high temperature and low flow conditions. Adjacent habitat consists of coniferous forest with mixed stands of hardwood.

This stream is stocked annually with trout by the Massachusetts Division of Fisheries and Game which provides a "put-and-take" sport fishery. Waterfowl and other game species are essentially similar in types and number to that found in the Tarbell Brook watershed.

The proposed diversion site would be located approximately four miles due east of the town of Royalston in an unpopulated area, three miles above the confluence with the Millers River. The project area will encompass about 400 acres, including approximately 330 acres of wetland and 70 acres of upland habitat.

The following private developments are located within the project area: An extensive private camping development consisting of approximately 50 trailers and attendent facilities and a gun club facility including a clubhouse, target range, and a one-half acre pond, just north of Winchendon Road.

(3) Tully Reservoir Diversion

The East Branch Tully River extends about 15 miles from its headwaters in southern New Hampshire to its confluence with the West Branch Tully River. Open waters along the stream, including Tully Reservoir, cover six miles. The total drainage area of this river is 56 square miles of which about eight are wetland, six are open water, and the rest upland habitat.

The river is of medium gradient with a section of slow moving water in the Long Pond area. Width varies up to 30 feet and depth up to 8 feet in some areas. Water quality is good (class B) and is classified as "good trout water" on a seasonal basis. Terrain surrounding the river is moderately steep and heavily forested with mixed deciduous and coniferous trees.

The East Branch of the Tully River is stocked annually with trout by the Massachusetts Division of Fisheries and Game which provides a "put-and-take" sport fishery. Waterfowl and other game species are typical of those found in the Tarbell and Priest Brook watersheds. Considerable hunting activity for birds, small animals, and deer takes place in the basin. Numerous wood roads and trails remaining from past logging operations provide good access for hunters and fishermen.

Recreation development potential is excellent and good white-water canoeing occurs below Tully Dam during periods of high water.

(4) West Branch Tully River Diversion

The West Branch of the Tully River, including Tully Brook north of Sheomet Lake, is about 8 miles long, extending from its headwaters in central northern Massachusetts to its confluence with the East Branch of the Tully River, $1\frac{1}{2}$ miles north of Athol. The West Branch is of a moderate gradient, and is up to 35 feet wide with depths up to 5 feet along its course. Open water areas, mainly Sheomet Lake, cover only $\frac{1}{2}$ mile along the river. Water quality is good (class B) and the river is annually stocked with trout by Massachusetts Division of Fisheries and Game. Total drainage area of the basin is about 19 square miles of which approximately 2 acres are wetland and the remainder upland.

The river flows through a relatively unpopulated and heavily wooded (mostly of mixed conifers and hardwoods) area. Wildlife found in this basin is similar to that of the nearby East Branch Tully, Priest and Tarbell Brook areas.

3. Environmental Impact of the Proposed Action

Northfield Mountain - Connecticut River

Diversion at Northfield Mountain may affect the aquatic life in the Connecticut River at the diversion point. Fishes, phytoplankton and invertebrate organisms of all life stages, may be entrained and/or entrapped at the pumping facility, whether diversion takes place or not.

The fish population, while composed of many species, contains only a few which can be regarded as being important to anglers. These are: pike perch (walleye pike), black bass, yellow perch and catfish. Studies by the Massachusetts Division of Fisheries and Game indicate that this reach of the river is underfished and the walleye population is probably almost completely composed of young fish descending the river from above Vernon, Vermont. The probability of great numbers of fish being transported into the pumps appears quite remote. This conclusion is based on several facts. One, only in a very limited part of the intake canal would the current be moving faster than in the main stream, thus older fish would not be carried into the canal against their will. Secondly, bass and catfish have specialized requirements as to where they build their nests, one of which is to locate outside of areas of strong currents. By the time the young leave the vicinity of their nest, they would be old and strong enough to avoid the canal. The other important sport fish, the walleye, apparently does not spawn in this reach of the river. It is quite probable that the eggs and young of minnows and suckers will be carried through the pumping cycle and will have a high percentage of survival. Until such time that a fishway is constructed to pass anadromous fish over the Turner's Falls Dam Sea-run fish will not be able to reach the intake canal. When that time comes, care must be taken to design a fish passage facility that will not allow the Lamprey eel over the Turner's Falls Dam. This action should be taken to insure that the possibility of larvel Lampreys entering the intake and transported to Quabbin would be remote.

The natural downstream flow in the Connecticut River during the spring runoff diversion period would be reduced by about 1%-2%, but is not expected to result in any detectable effects downstream of the diversion site at Northfield Mountain.

At the maximum diversion rate the river would be lowered approximately 2-3/8" at Montague City. This is a minor fluctuation in relation to natural and present man manipulated changes in water levels and would have no measurable impact on wetlands associated with the river.

As the bulk of the river's present nutrient load is picked up downstream of the diversion point, little or no effect on the river load would be brought about by diversion at Northfield.

Northfield Mountain Diversion - Quabbin Reservoir

There can be little doubt that increased levels of nutrient chemicals will be detected in Quabbin Reservoir after the implementation of the Connecticut River diversion via Northfield Mountain. Phosphorus increases are possible, but not probable. Increases in available carbon, on the other hand, are quite probable, if only due to the relatively high alkalinity of the Connecticut River. Also, the fact that fecal contamination of the Connecticut River does occur increases the likelihood that complex organic molecules will be introduced into Quabbin and possibly into Wachusett where they will become part of the nutrient pool. The future abatement of pollution in the Connecticut River will contribute significantly to the lowering of any such nutrient addition to the reservoir through diversion.

It is important to note that current nitrogen, phosphorous and carbon levels in Quabbin are sufficient to support larger phytoplanktonic populations than presently exist. Increased levels of these nutrients do not necessarily mean, then, that higher concentrations of algae in Quabbin can be expected as a direct result of the diversion. It is quite possible, however, since nitrogen, phosphorous and carbon appear not now to be limiting, that the Connecticut River diversion may increase the levels in Quabbin Reservoir of some now unknown limiting growth factor, such as a vitamin. Additional studies on limiting growth factors in both Quabbin Reservoir and Connecticut River water is planned by the MDC.

There is no reason to believe that undesirable algal species will be introduced into Quabbin Reservoir by either diversion. Any changes in the current algal populations in Quabbin will most likely be the result of the response of present populations in Quabbin to changing levels and kinds of nutrients brought about by the diversions.

The proposed diversion of Connecticut River waters into Quabbin Reservoir present a possibility of having a negative ecological impact upon the fisheries of Quabbin. Undesirable species can be introduced into Quabbin Reservoir if Connecticut River waters are diverted. The consequences of introducing undesirable species could disrupt the present ecological balance of species in Quabbin. If the present salmonid population is decimated by undesirable species competition, a warm water fish population may result with the likelihood that the number of angler trips by sports fishermen to Quabbin Reservoir could decline. This in turn will reduce the harvest and further influence ecological balance. The issue is not solely a reduction of the standing crop of total fishes in Quabbin Reservoir, but the disruption of the present success in the management of a salmonid fisheries program. Because of these concerns studies on methods of excluding undesirable species are now being carried out by the MDC in cooperation with the Massachusetts Division of Fisheries and Game.

Increased concentrations of organic molecules in Quabbin as a result of the Connecticut River system diversion may affect the dissolved oxygen content of Quabbin waters due to the oxygen demand created by these additional molecules. The magnitude of any overall decrease in oxygen in the hypolimnion of Quabbin Reservoir, however, is not expected to cause significant changes in the present ecology of Quabbin Reservoir. Localized depletions of oxygen in Quabbin Reservoir have been periodically noted over the past half dozen years as a result of the present Ware River diversion. These depletions have been observed only in the southern part of the eastern arm of Quabbin, and have been short lived. The proposed diversions may be expected to produce similar, localized phenomena. The salmonid fisheries in Quabbin are not expected to be effected by any lowering of dissolved oxygen which is localized in the upper portion of the middle arm and in the eastern arm because they are typically found in the main body of Quabbin.

Because of the number of factors governing the disposition of pesticides in surface waters, it is not surprising that only small traces of pesticides were detected in this study. Analyses for aldrin, BHC, DDT, dieldrin, endrin and other pesticides during the 1960's show little or no residues in the water. Finally, the findings of Lichtenberg et al. (1970) in a 5-year summary of pesticides in surface waters of the United States report only trace amounts (less than 0.1 ppb) of pesticides in the Connecticut River.

A prediction with some certainty can be made about the ecological effects of pesticides in the proposed diversions. The Massachusetts Division of Fisheries and Game has data that indicate significant levels of DDT, endrin, dieldrin and PCB's in the tissues of lake trout taken from Quabbin Reservoir. These pesticides in lake trout reflect the expected concentrations by the food chain if traces of pesticides are already available in the reservoir ecosystem. Nor were the residues of DDT in fish from the Connecticut River (Lyman et al., 1968) any higher than those reported for the fish in Quabbin Reservoir. While more extensive monitoring of the waters, muds, and biota of both the Connecticut River and Quabbin Reservoir for pesticides would increase the certainty of prediction, it is highly improbable that the proposed diversion will have any important environmental effects.

Somewhat different from the above impacts is the much more general question of ecological balance. This question cannot be answered in any but very general terms. That any change in an ongoing ecological system is effected and becomes persistent is good indication that a shift in ecological balance has been achieved. The probabilities of some of the more important, possible changes in Quabbin due to the proposed diversions have been discussed earlier. However, what all the effects of any shift in ecological balance may actually be cannot now be predicted. For example, an increase in Quabbin of "trash fish" populations may result from slight shifts in competition patterns which in turn may result from the introduction of species into Quabbin by the Connecticut River diversion. The salmonid population could remain essentially unaffected. However, the number of angling trips to Quabbin may very well decline. The harvest of fish would then be reduced, and could conceivably be lowered to such an extent that a second shift in the ecological balance would be realized. This second shift, or any subsequent shift, might in turn directly affect the salmonid population. Thus, sociological and biological events can interact to produce a series of complex phenomena which cannot be predicted in any but the most general form. It must be remembered, however, that if Quabbin is not augmented with additional water the risk of ecological disaster far outweighs the above points of concern with the diversions.

The initial volume of water represented by any diversion plan would be a very small percentage of the total Quabbin capacity during the first few diversions. This time frame would be available to intensively study the actual impact of diversion while its potential to cause changes in the reservoir would be slight. Results of this monitoring period would be used for operational guidance in future diversions.

The impacts of the proposed diversions into Quabbin or Wachusett Reservoirs are impossible to discuss in any but very general terms until such a time as the specific impacts discussed in this statement can be more fully defined by future actions. On the basis of current data, the possibility of a degeneration in turbidity in Wachusett deserves some mention due to the importance of turbidity in any contemplated future treatment of Wachusett waters prior to their final distribution to consumers.

<u>Public Health Aspects - Quabbin Reservoir</u>

Coliform bacteria are indicators of possible human fecal contamination and therefore of the possible presence of human pathogens, including bacteria and viruses. Coliform bacteria are not themselves, however, pathogenic. It is reasonable to assume that concentrations of coliforms will increase in Quabbin Reservoir as a direct result of the Connecticut River diversion. Therefore the possibility of finding agents of human infection in the area of Shaft 12 in Quabbin will also be increased by the diversion. The measure of real risks to public health associated with this possibility is, however, a function of a number of other variables. These variables include the general health of populations contributing to the fecal pollution of the Connecticut River, treatment of water before its entry into Quabbin, residence time of this water in Quabbin, dilution of diverted waters by Quabbin waters; and finally, treatment prior to final distribution.

While the MDC is currently planning, according to a Massachusetts Department of Public Health directive, to chlorinate diverted waters prior to their entry into Quabbin, varying turbidities of these waters, and the resultant inefficiencies of chlorination, will ensure the possibility that pathogens imbedded within suspended debris will find their way into Quabbin. Chlorination of diverted waters prior to entry into Quabbin will probably be less important a means of controlling the introduction of these pathogens than will the implementation of present pollution abatement plans for the Connecticut River.

Even with the implementation of present abatement plans an important question is how long diverted waters can be expected to remain in Quabbin. In general, the natural purification processes of a lake will reduce the coliform concentrations in proportion to the length of time these bacteria are in residence in the lake. The die-off rates of coliform bacteria are generally considered to be similar to die-off rates of pathogens. While recent research indicates that there is not necessarily a direct correlation between the die-off rates of coliform bacteria and pathogens, it is generally assumed that resident times of several weeks provide reasonable disinfection (Fair, Geyer, and Okun, 1968).

Model studies thus far indicate that diverted waters will have reached the general area of Shaft 12 within 2-3 months of the time they are introduced into Quabbin. Portions of these waters will be mixed with waters derived from the southerly portions of the main body of the reservoir as they are taken into Shaft 12; other portions will continue in a southward flow to mix eventually with the waters in the western arm. While it can be expected that significant die-offs of pathogens will occur within a 2-3 month residence in Quabbin, and that maximum dilutions of diverted waters will probably be realized within one diversion cycle, the possibility that some pathogens may find their way into the Quabbin aqueduct has to be assumed. The possibility that some pathogens will find their way into the Chicopee outlet at Winsor Dam also has to be assumed; however, because preliminary laboratory model studies indicate it will take about 7 months for diverted waters to reach Winsor Dam, and because of the greater dilution of these waters which would then have taken place, the probability of detecting pathogens at the Chicopee aqueduct would be lower than that of detecting them at the Quabbin-Wachusett aqueduct.

Because model studies to date have not taken into account the effect of winds on residence times of diverted waters, and because pertinent information of the die-away phenomenon is by no means complete, it is not now possible to predict the actual number of pathogenic organisms which may possibly find their way into the Quabbin-Wachusett and Chicopee aqueducts as a result of the Connecticut River diversion.

Because coliform concentrations within the Tully System are comparable with the minimal concentrations already observed in Quabbin, and because current model studies indicate that the residence time for Connecticut River diversions in Quabbin will not be reduced appreciably by the Tully System diversion, the impact of the Tully System diversion will be to reduce further any public health hazard associated with the Connecticut River diversion.

It is important to note that any pathogens which do find their way into the Quabbin-Wachusett aqueduct will be subjected to dilution by Wachusett waters as well as to the self-purification processes of that reservoir. Given the dilutions and residence times of diverted waters in both reservoirs, we conclude that while the introduction of pathogens into Wachusett Reservoir is possible, it is improbable that they will be detected in Wachusett. Finally, any enteric organisms which may be present in Wachusett as a direct result of the contemplated diversion may be easily destroyed by existing or contemplated chlorination within the distribution system.

The presence of mercury at all sampling sites suggests that it is reasonable to assume that mercury is a component of the waters of this region. While the levels are generally low and thus pose no immediate hazards, the possibility of significant concentrations in the food chain must be assumed. Indeed, data from the Massachusetts Division of Fisheries and Game indicate levels of mercury in fish taken from Quabbin Reservoir to be in the range of $10^2 - 10^3$ ppb, in this regard being similar to levels found in fish in the Connecticut River. Several peak values for mercury in excess of 5 ppb have been found in some locations, including the Millers River and Quabbin and Wachusett Reservoirs. Most of these values occurred earlier in the year, and recent data indicate lower values. The reasons for these values are unknown, nor can the present study, due to the sampling situation, define any possible sources. Our conclusions on the impacts of the proposed diversions, however, must be based on comparative data for the proposed donor and receiver systems. On the basis of the data, we must conclude that no public health hazards due to higher levels of mercury can be expected from the proposed diversions. Indeed, the data suggest that lower levels in water exist in the proposed donor systems.

Pesticide information was reviewed. The findings confirm the position that the Connecticut River waters would not present a public health hazard if diverted into Quabbin Reservoir. In the first place the amounts of pesticides are too low, and secondly the evidence indicates trace amounts to be present in Quabbin Reservoir already. Therefore, the purposed diversion would not introduce pesticides into a reservoir that was already free from such compounds before the diversion.

Our data on radioactivity leads us to conclude that no public health hazards will result from the diversions of Connecticut River waters or Tully System waters into Quabbin Reservoir. The Lawrence Experiment Station has been testing Connecticut River water as part of the cooperative efforts of the Tri-State Commission for some time, and has detected neither ^{226}Ra nor ^{90}Sr in the water. Also surface waters, including reservoirs, from all over Massachusetts have been treated in the spring and fall, and no presence of ^{226}Ra or ^{90}Sr has been detected. On the other hand, some of the STORET Data (Retrieval Date 69/02/27) for 1960's show Connecticut River water with total beta activity in excess of 10 uuc/liter. This is not true for the more recent data. These discrepancies are common for Connecticut River data, and point out the need for continual monitoring. Such continual monitoring is also desirable in view of the future operation of a nuclear power plant at Vernon, Vermont. Studies support the conclusion that, in view of existing guidelines, we see no immediate or long-range public health hazards from radioactivity in the donor systems.

The risks to human health which are inherent in the consumption of any surface waters cannot, of course, be completely eradicated. However, given man's past experience with public water supplies and his present technology, we conclude that those risks which can be associated with the proposed diversion are reasonably comparable with those generally taken in the consumption of Massachusetts surface waters.

Based on available evidence, there is no reason to anticipate any public health hazards to the donor systems resulting from the proposed diversions. A positive impact on the Millers River system is possible , the main reason coming from the probable decrease in any pathogens as a result of the impoundments. Impoundment of water results in a decrease in pathogens, due to die-off. However, while coliform bacteria are present in these waters, we have no direct evidence of any pathogenic organisms.

Millers River Alternatives

Diversion from the Millers River Watershed by either Alternative #1, #2, or #3 is expected to induce minimal effects since the total water volume removed would be insignificant (1% - 2%) compared to natural flow in the Connecticut River. Another factor is that diversion would not take place unless a substantial flow (at least 17,000 cubic feet per second) is being recorded at the Montague City gaging station.

The Tully and Millers River systems will be affected more than the Connecticut River, with maximum effects on flows below the diversion sites and at the confluence of the Tully and Millers Rivers. Tarbell Brook and Priest Brook diversions will reduce peak flows at South Royalston during diversion days. On a monthly basis, up to 17% of the flow will be diverted.

On a daily basis, up to 48% of the normal flow at South Royalston may be lost during the diversion period. Most months will have some days with no diversion loss at all because the control flow requirements cannot be met. At the confluence of the Tully and Millers Rivers, diversion effects on flow will be most pronounced. Up to 31% of the monthly flow may be diverted during an average year, and on especially high runoff periods, 50% of the daily flow may be diverted.

Millers River Diversion, Millers - Tully Diversion, Tully Complex Diversion Impact on Quabbin Reservoir

All these proposals, with the exception of Alternate No. 3 with it's high quality water, will depend in part on the "treatment plant" capacity of Quabbin Reservoir. The magnitude of this capacity is unknown, but the fact that it has efficiently handled waters from the Ware River Diversion for the past 30 years indicates that some additional capacity is present. It cannot be predicted with certainty that dilution with ambient reservoir volume alone will completely restore water quality. It is assumed that some sedimentation, transportation and evaporation of materials must occur to improve water quality. Considering future water inputs to Quabbin Reservoir it must be borne in mind that Alternate No. 1 or No. 2 would not be implemented until water quality of the Millers River meets all public health as well as environmental standards present at Quabbin. It is useful to know that fish species now found in the Millers River watershed are generally similar to those present in Quabbin Reservoir so that a large scale shift in Quabbin fish populations because of a new species introduction is not expected if one of the Millers River diversions is realized.

Water Quality Monitoring System

All of the diversion proposals being considered, including Northfield Mountain, incorporate a sophisticated water quality monitoring system in their design. The system, although primarily intended to insure public health standards are continually met, can be used to measure other elements found in the water which would have an influence on the Quabbin environment.

Alternative No. 1 - Millers River Mainstem

Several cold water species such as trout are now only found in the upstream waters while the warm water species have a wider distribution. Completion of pollution control facilities will make the river a more attractive target for the fisherman. Trout fishing in the headwaters is now a "put and take" proposition and is expected to remain so in the future. Warm water fish may expand in numbers, but experience elsewhere indicates that most warm water fish populations are lightly fished and under utilized. Based on these considerations, water cleanup will undoubtedly increase fishing opportunity downstream of the diversion point. Diversion will take place only during periods of high flow so that fish passage would not be obstructed by the project during the remainder of the year (they are presently locked in segments of the river by major dams at Athol, Orange, and Millers Falls).

Other possible effects on the Millers River below the diversion point could include a slight temperature rise during the latter part of the diversion period, a lessening of the sediment load, and a partial loss in flushing action. No changes are predicted for vegetative cover which in turn would assure that wildlife habitat would remain unchanged.

Wetlands by their definition are wet all year round so that no impact would be expected on them. Higher areas which presently receive water infrequently probably will receive shorter periods of inundation.

Alternative No. 2 - Tully - Millers River Diversion

This alternate essentially results from the combining of Alternate No. 1 with the addition of a supplementary diversion from the East Branch of the Tully River to the diversion point on the Millers River discussed under Alternate No. 1. There would be no additional impact on the Millers River below the diversion point downstream to the confluence of the Tully River other than that discussed under Alternate No. 1. Below this junction the loss of water from the Tully to the Millers would be approximately 5% of the total Millers flow based on the maximum monthly flow in the Millers River in an average year. Upstream the reduction in flow of the Tully River between Tully Dam and the confluence of the Millers River would be approximately 23% of the monthly average for March, April and May.

It is expected that the environmental impact on the Tully River and the East Branch Tully River below Tully Dam will be similar to that discussed under Alternative No. 1. This is due to the fact that comparable percentages of water will be diverted and the watersheds are similar in topography and other surface characteristics.

The environmental impact on the Millers River below its confluence with the Tully River will be slightly increased over that discussed under Alternative No. 1 since diversion will take place from the Millers River and from the East Branch Tully.

Alternative No. 3 - Tully Complex Diversion

(1) Tarbell Brook Diversion

If implemented, the project will seasonally inundate 40 acres of wetland habitat to a depth of 5 feet, including $\frac{1}{2}$ mile of free flowing stream. The weir would prevent free movement of stocked fish as well as resident species. Diversion of natural high flows may reduce canoeing potential.

(2) Priest Brook Diversion

If implemented, the 400 acre site will be cleared and seasonally inundated, including all of Priest Brook above the proposed damsite, and short reaches of Scott and Town Brooks. The dam would prevent free passage of stocked fish as well as resident species. The entire project area will be subject to periodic inundation and drawdown. During certain times of the year, natural stream flow into the Millers River would be reduced. A 40 acre waterfowl pool would be made possible by the creation of a low weir above Deland Road.

Potential for recreational opportunities within the project area would be limited to hunting, fishing, hiking, nature study, etc.

(3) Tully Reservoir Diversion

The proposed diversion site would be located within the existing Tully flood control reservoir. The existing pool forming Tully Lake would double the present surface area to 600 acres during the summer recreation season. The pool would subsequently be gradually drawn down after Labor Day. Since Tully Lake would become a domestic water supply source, the lake bottom would be cleared and stripped of organic material in order to protect the water quality.

With the proposed plan of diversion from Tully Reservoir to Quabbin, up to 25 percent of the storage capacity of Tully will be used for the dual purpose of flood control and water supply. During the spring freshet season, this storage will be filled if, and when, inflows exceed downstream requirements and diversion capacity. This stored water will later be diverted to Quabbin, making the full flood control storage capacity of Tully available for the fall hurricane season.

Flood control storage requirements are the greatest in southern New England during the fall hurricane season and secondly in the spring during the snowmelt season. The filling of the multipurpose storage during the spring high flow period will, in fact, provide incidental flood control. Analysis of streamflow records indicate that less flood control storage is required during the summer season than the rest of the year for a comparable degree of protection. As a result, in some Corps reservoirs in New England, some seasonal encroachment on flood control storage has been recommended for other worthwhile uses.

If implemented, the proposed project would cause periodic inundation of 300 acres of wetland, which are presently subject to seasonal inundation during natural flood conditions. High flows below Tully Dam during the spring would be reduced and may limit the length of the white-water canoeing season. Following the fall drawdown, some lake bottom would be exposed. Recreation development potential for summer day use facilities is high with excellent opportunities for various outdoor activities. Less than 50 acres of upland game habitat would be lost, while fishing and boating values associated with this project would increase.

The environmental impact on the proposed diversion site would be essentially the same as at Tarbell Brook. About 13 acres will be permanently inundated, which includes ½ mile of free flowing river. This ½ mile stretch of trout stream would be replaced by a marginal waterfowl area. Recreation opportunities would remain limited after implementation of the proposed diversion plan.

Under Alternative No. 3, Tully Complex, the mainstem Millers River would receive less water than under present conditions. Major diversions would be implemented during March, April, May, November, December and January. Less water would ultimately result in less dilution of the pollution load; however, pollution is a more serious circumstance during summer and autumn, at which time diversion would only take place during excessively high flows. Thus, diversion probably would have a minimal effect on the water quality of the Millers River.

Adopted water quality classifications are based on natural low flow conditions. Design of sewage treatment plants to meet quality standards, therefore, must be based on these same low flow conditions. Diversions of flow during high flow conditions thus would have no effect on such plants particularly since pollution abatement programs will ultimately reduce the present pollution load.

Diversion is not expected to significantly affect sport fishing above the confluence with the Otter River. The sport fishery is presently located primarily upstream of the diversion sites and the amount of diversion expected from Tarbell Brook is insignificant compared to the total water volume available in the mainstem of the Millers River.

Effect of diversion on white-water canoeing may be beneficial during periods of extreme high water; however, diversion may shorten the season during low-flow periods in late spring. Diversion would have no effect on canoeing above the confluence with Tarbell Brook.

For Alternative No. 3, the pool formed on East Branch Tully River and Priest Brook would be subject to fluctuation. For example, the entire pool in a normal operation may be filled and emptied within a period of less than 3 months. Under such pool fluctuations, the possibility of erosion does exist. These fluctuations, however, are not expected to cause bank sloughing. The erosion instead would be similar to roadbank erosion caused by surface runoff.

Diverting maximum design capacity of 90 c.f.s. from Tarbell Brook and 30 c.f.s. from Priest Brook will affect the stage of the streams below the diversions less than a foot. Nearly all riparian rights along the reaches of Tarbell and Priest Brooks affected by the proposed diversion are controlled by the Corps of Engineers Birch Hill Dam.

Since operation of Birch Hill Reservoir and Tully Reservoir prevent overbank flooding, the proposed diversions will have no effect on groundwater recharge from flood plains below the reservoirs.

Skimming flood flows from Tarbell and Priest Brooks to Tully Reservoir will have no effect on stream flow above the points of diversion, so there will be no change in overbank flooding.

At Priest Brook, storage would be evacuated as soon as possible to Quabbin Reservoir. Therefore, storage would only be utilized about 3 months and little opportunity exists for eutrophication. In the East Branch Tully pool at Tully Lake, the stripping of organic material and the observed water quality characteristics appear to preclude potential eutrophication.

On Tarbell Brook and West Branch Tully River, maintenance of a pool is considered only to provide some fisheries or wildlife enhancement. Both of the storage impoundments created on these streams would be shallow and subject to temperature increases which could aid in the growth of flora. If any problems developed from maintaining these pools, all water could be released following the diversion period.

Background Data - Biological Studies

General: It seems appropriate to include in this Preliminary Draft Environmental Statement more detailed information gained through the findings of the biological studies conducted during the course of the planning process. There are two principal reasons for this approach; one the reader will have the advantage of seeing the basis for the conclusions presented in the earlier portion of this section, and secondly will get a feel for the tremendous amount of biological and associated data generated by the two contracted studies. The following pages delineate some of the more important findings of each study.

Northfield Mountain and Millers River Studies

One of the studies conducted on the donor and receiver systems was a cooperative effort of several organizations to generate and evaluate extensive data on the Quabbin and Wachusett Reservoirs and the Connecticut and Millers Rivers systems, with the objective of making predictions on the impacts of diverting portions of these riverine systems into Quabbin Reservoir.

Field and laboratory data included approximately 100 parameters, including chemical, physical, biological, and pesticides data. In addition, radiological data, hydrodynamic studies, fisheries information, and pollution abatement plans were considered and evaluated. Finally, other pertinent data available from both public and private sources, especially on the Connecticut River, were evaluated in the light of the objectives of the study.

Central to the evaluation was the development of a qualitative model of reservoir dynamics. Such events as evaporation, sedimentation, transformations, and direct transfer of materials from potential donor to receiver and finally to the distribution system were discussed. Any predictions on water quality as a result of diversions were qualified by our present knowledge of the underlying dynamics.

Dilution of riverine waters by ambient reservoir volume alone will probably not be sufficient to insure an acceptable water quality in Quabbin Reservoir. Fallout of suspended materials and the "treatment plant" capacity of Quabbin Reservoir are expected to result in an acceptable water quality.

A general summary of the impacts of the proposed diversions on Quabbin Reservoir is shown in Table 1. The potential magnitude of a given impact upon Quabbin Reservoir is generally higher with the proposed Connecticut River diversion than with the proposed Tully River system diversion. Predictions on the temporal aspects of any impacts cannot be made at this time.

Table 1. Summary of Probable Impacts of the Proposed Diversions on Quabbin Reservoir

Note: This summary does not predict the duration of the impact.

Description of Impact	Relative Probability Impact Will Occur: No significant change over existing conditions	Possible but Probability Low	Probable	Probability High
Increase in Nutrient Chemicals		T	C	
Increase in Eutrophication		T	C	
Modification of Present Equilibration			C T	
Introduction of Undesirable Species		T		C
Increase in Coliform Bacteria		T	C	
Increase in Human Pathogens		C T		
Interference with Water Treatment at Quabbin		T	C	
Increase in Levels of Toxic Materials	T	C		
Increase in Levels of Radioactivity	C T			
Increase in Levels of Pesticides	C T			
Increase in extent and magnitude of oxygen depletion		T	C	

C = Connecticut River Diversion   T = Tully System Diversion

As a convenience in making evaluations of the probable impacts of the proposed diversions, the period 1972-2000 was divided into four phases. Phase 1 (1972-1976) is the period before diversion of the Connecticut River. The volume of Quabbin Reservoir will decline during this period. Phase II (1976-1980) represents the period for the beginning of the Connecticut River diversion; the Tully River diversion is not yet operative. The reservoir volume will increase during this period. The period 1980-1989 (Phase III) represents a period when both diversions are operative, and the reservoir volume continues to increase. During the final phase (Phase IV, 1989-2000) both diversions continue to be operative but reservoir volume declines. Probable, major, long-term trends in Quabbin Reservoir for this overall period are summarized in Table 2.

The greatest potential for both ecological and public health impacts on Quabbin Reservoir is seen to exist with Phase II. Because of declining reservoir volumes, Phases I and IV will show some deterioration of the reservoir.

Impacts of the proposed diversions on the two donor systems will differ. We expect no significant changes in the hydrology, water quality or general ecology of the mainstem Connecticut River. Temporary storage of Connecticut River water in the upper reservoir of the Northfield pumped storage facility may cause some changes in water quality. However, the impacts of these changes after diversion to the receiver or return to the donor will probably be minor. In the

Table 2. Probable Major Long-Term Trends in Quabbin Reservoir

Phase	Trend
I (1972-1976)	Progressive deterioration of northern part of middle branch, and the eastern branch.
II (1976-1980)	Shift in ecological balance, especially middle branch. Water quality changes probable. Volume increase may actually retard some deterioration from Phase I. Potential public health hazard greater than Phase I.
III (1980-1989)	Probable improvement in water quality. Further reduction in deterioration in northern part of middle branch begun in Phase I. Potential public health hazard reduced over Phase II.
IV (1989-2000)	Progressive deterioration of entire reservoir.

Millers River system we envision probable changes in the hydrology, in general water quality and in the ecology. These changes will be a consequence of the diversion of relatively large volumes of higher quality water and the impoundment of waters. Because of the proposed cleaning up of the Millers River, changes in water quality in the mainstem Millers River will not be a long term impact. Changes associated with the impoundments will have both long term and short term impacts. There will be no significant public health impacts on the donor systems.

Realistic appraisal of a no-diversion alternative is also important for this project. Under average inflow conditions and projected demand, Quabbin Reservoir will be dry by 1985. At some time before this year, water quality will decrease, eutrophication will increase, and fish populations will change. Also at some point before total water depletion in 1985, the reservoir will not be an acceptable public water supply. As a related problem, the losses in volume and water quality of Quabbin water will increase the risks of diversion if a diversion is delayed by only a few years. We conclude that the no-diversion alternative is unrealistic unless other alternatives, outside the scope of the present project, offer better solutions to the projected Boston metropolitan water supply problem.

Environmental Aspects

Impact on Hydrology

This section attempts to outline what will happen to the hydrology of the donor and receiver systems from the year 1972 to about 2000.

Without any additional inputs over those already operative, and assuming Wachusett Reservoir will be kept at a reasonable operational level (elevation 380-385 feet), Quabbin Reservoir under average inflow conditions and projected demand, will be dry by 1985 (Figure 1). The present volume of Quabbin represents about 50% of maximum capacity. Assuming that a Connecticut River diversion is implemented in 1976, and a Tully diversion by 1980, Quabbin Reservoir will increase in volume for about 20 years and then return to its present volume by 1998. These figures are based on current estimates of projected demands (450 mgd in 1992) and the assumed inputs to the system (see Table 3).[1] Assuming these implementation dates for the two diversions, and the figures as outlined, four distinct time periods during which the volume of water impounded at Quabbin Reservoir will undergo major changes are as follows:

1972-1976 (Phase I)	No Connecticut River or Tully System diversion. Quabbin water consists of about 11% Ware River water. Volume steadily declines.
1976-1980 (Phase II)	Connecticut River diversion implemented. Volume steadily increases. Ware River diversion represents decreasing proportion while Connecticut River represents an increasing proportion of total volume (Table 4).
1980-1989	Connecticut River and Tully System diversions operative. Volume of Quabbin reaches peak of about 87% of its maximum capacity (Figure 1).

1. Figures supplied by Construction Division, MDC and U. S. Army Corps of Engineers.

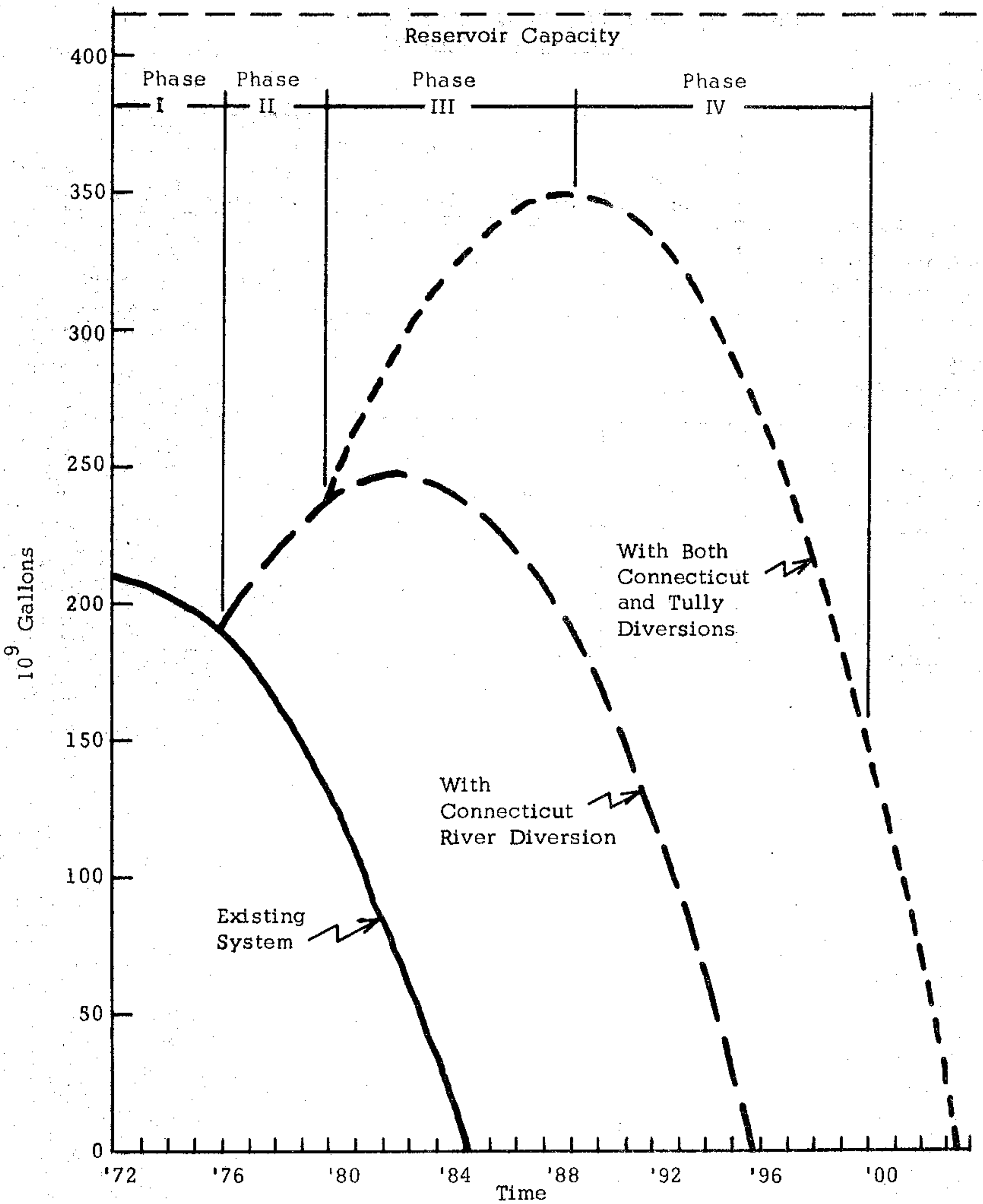


Figure 1. Projected Quabbin Reservoir Volumes With and Without Diversions

Table 3 Annual Inflow to Quabbin Reservoir From Various Sources

	Quabbin Watershed	Ware Diversion	Connecticut River Diversion	Tully System Diversion	Total
Average Inflows per Year (10^9 gal)	85	11	26.3	17.5	139.8
1972 Relative Input (%)	89	11	-	-	100
1976 Relative Input (%)	70	9	21	-	100
1980 Relative Input (%)	61	8	19	12	100

Table 4. Proportion of Quabbin Reservoir Water Originating from Various Sources at the End of a Given Year (%)

	Quabbin Watershed	Ware Diversion	Connecticut River Diversion	Tully System Diversion
1972	88.5	11.5		
1976	81.0	10.5	8.5	
1978	74.1	9.6	16.3	
1980	68.2	8.8	18.4	4.6
1982	64.0	8.3	18.7	9.0
1984	62.3	8.1	18.7	10.9
1986	61.6	8.0	18.7	11.7
1988	61.2	8.0	18.7	12.1
1990	61.0	8.0	18.7	12.3
2000	60.8	7.9	18.8	12.5

This Table is based on the following assumptions:

1. Average annual runoff from Quabbin watershed each year
2. Average annual diversion volumes each year
3. Reservoir outflow is comprised of water from each source in the same proportion as water in storage from that source is to the entire contents

1989-2000	Quabbin Reservoir volume steadily declines (Figure 1).. Relative proportions of waters originating from various sources becomes stabilized (Table 4).

During the year 1971 the level of Wachusett Reservoir dropped significantly. This was caused by lack of diversion of Quabbin Reservoir water into Wachusett Reservoir for a period of time because of maintenance operations. It is assumed that the volume of Wachusett Reservoir will be kept at a reasonable working level, because drastic reduction of its volume might impair water quality. Therefore we visualize no impact by the proposed diversions on the hydrology of Wachusett Reservoir.

Impoundments to be formed by the construction and operation of the diversions will vary greatly in area and duration of water storage. Tarbell Brook weir will impound during the summer a 28-acre pool with a maximum depth of 9 feet, at the spillway, and much of the area with depths less than 5 feet. Fluctuations in pool elevation will be up to 2 feet above spillway elevation during high flows. Priest Brook dam will be operated as a temporary reservoir, filling only when the combined diversion water from Tarbell and Priest Brooks exceed the 120 cfs pumping capacity at Priest Dam. When filled to spillway crest elevation, the pool will cover 400 acres with a maximum depth of 25 feet. Using data from an average year, for example 1943, the pool would be empty until mid-March, increase to 240 acres by March 31 and then become empty again by mid-April. After being empty for 4 days, it would fill again and fluctuate between 90 and 260 acres during the month of May. After diversion stops on June 2, the pool would empty in 6 days. The pool would remain empty throughout the summer and may fill partially in November for a few days. A wildlife conservation pool will be maintained in the middle of the cleared reservoir area, when the water supply pool is emptied.

Tully Dam will be operated in a manner similar to the operation of Priest Dam, with rapid fluctuations in reservoir area and volume. After June 15, the current plan is to maintain a summer recreational pool of 620 acres (maximum depth of 48 feet) through Labor Day. There would be no diversion during this period because of water-contact sports use of the pool. After Labor Day, the pool would be emptied to its winter level of a nominal nine-foot depth to keep the gates from freezing. Long Pond would also be flooded during high water storage and then return to pond status when the reservoir empties. West Branch Tully River Dam would be similar to Tarbell Brook installation. A 13-acre pool would be created and maintained by the overflow weir at the pumping station. Only nominal fluctuations in water depth would occur there.

In summary, the operation of the Priest and Tully Dams would cause widely fluctuating pools during March, April and May and sometimes in late autumn. Priest Reservoir would be dry during the summer and Tully Reservoir would have a 620-acre pool during this time. Tarbell Brook and West Branch Tully River would have small pools which would be drained each autumn.

The creation of the impoundments which are a part of the Tully Diversion system may tend to increase groundwater recharge in the Tully area. Although most of the land surface in this region is covered by glacial till deposits, there are glacio-fluvial deposits of sand and gravel adjacent to the several stream channels involved. These deposits are readily receptive to the intake of water and the annual draining of the large pools will help to maintain an unsealed bottom over much of the pool area. The magnitude of recharge water volume will depend on the extent of the deposits and head of water on them in addition to their permeability. The amount of low flow augmentation resulting from the recharge of these coarse deposits will depend on the proportion of recharge water that penetrates deeply into the underlying faulted gneiss and granite bedrock. There should be some flow augmentation from the surficial deposits during the early part of the summer season.

As water of lower quality is introduced from a donor system into a receiver system, there will most likely be a loss in water quality in the receiver system. This loss of water quality (Figure 2) is due to various materials in the water. These materials include ions, suspended inorganic materials, organic debris, and living organisms. The fate of these materials is shown in Figure 3. These pathways are not mutually exclusive; for example, a DDT molecule could take all four pathways. What happens to the various materials is a function of many mechanisms. One of the central problems of ecology today is to trace the flow of materials from the various compartments of an ecosystem.

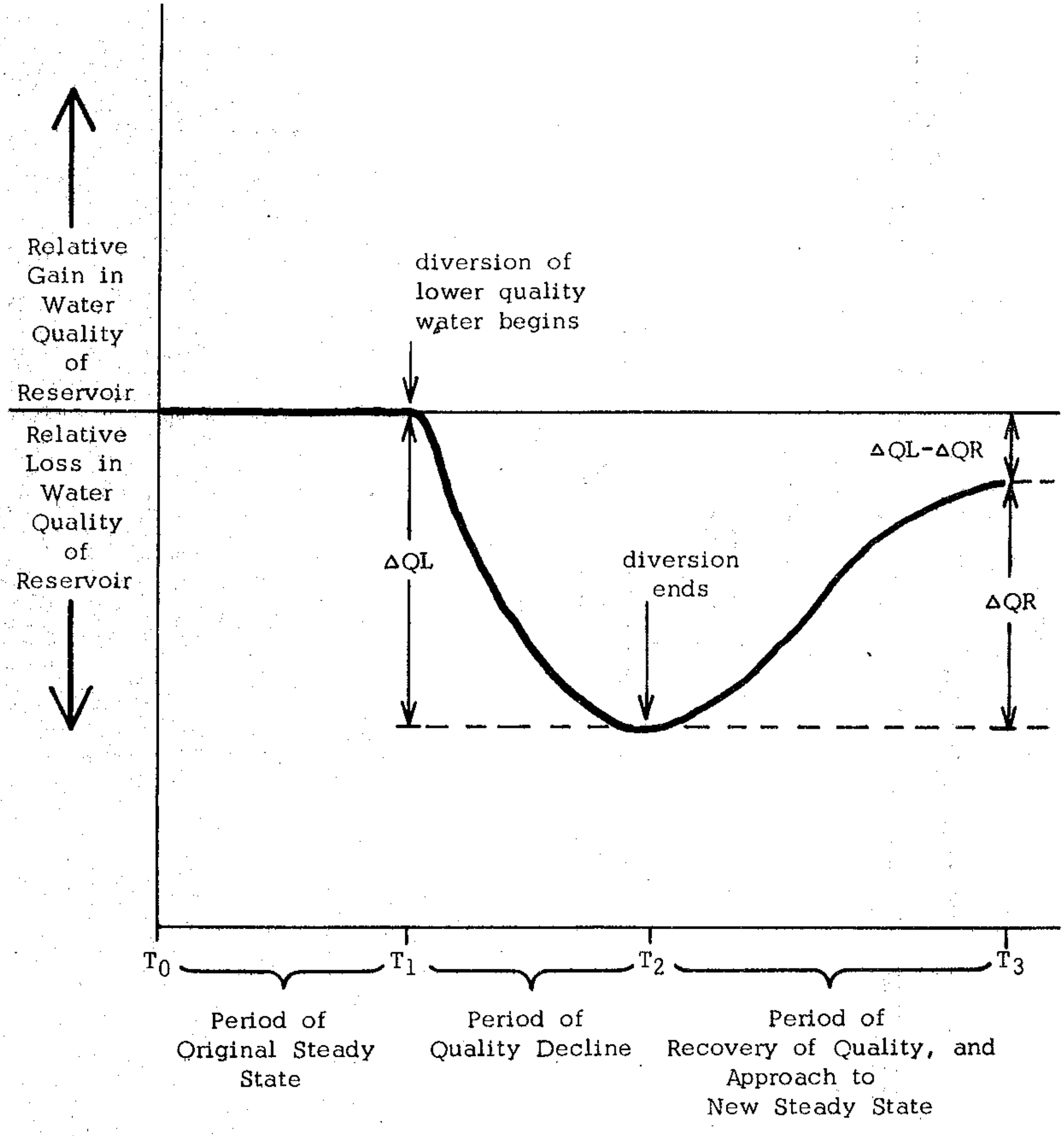
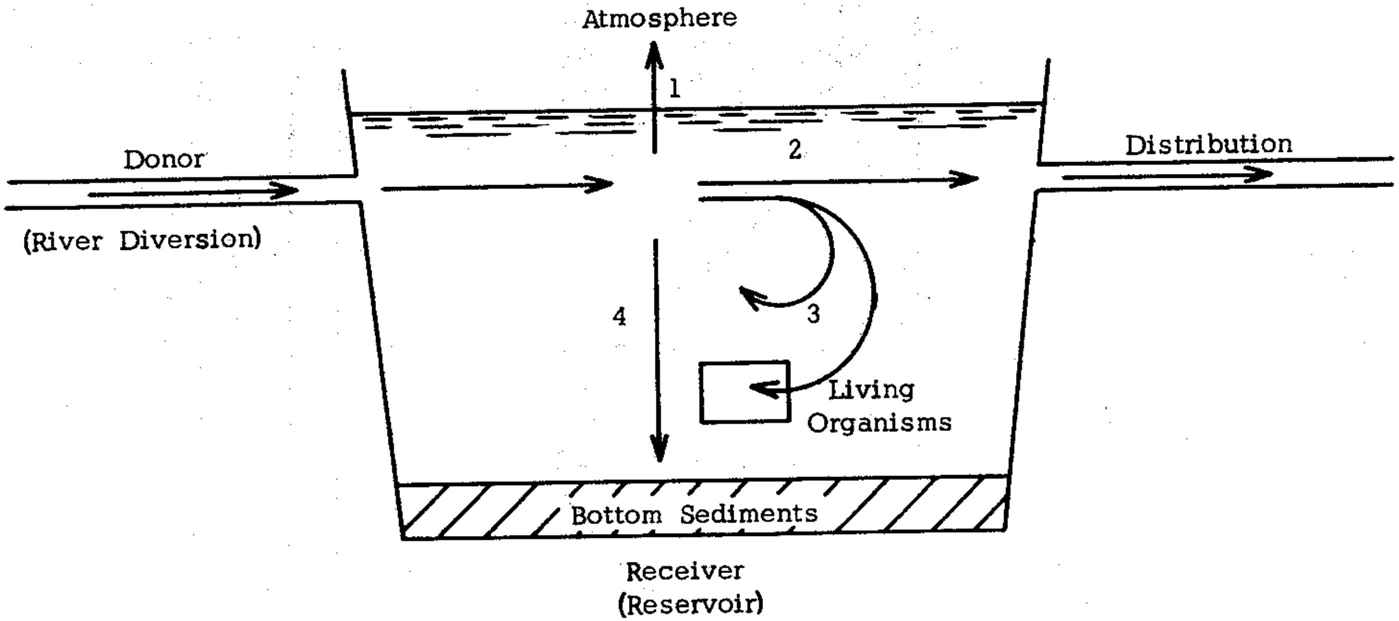


Figure 2. Generalized Qualitative Model of Diversion



1. Evaporation to atmosphere.
2. Transfer (no change).
3. Transformation, either with or without the involvement of living organisms.
4. Deposition to bottom sediment.

Figure 3. <u>Schematic Diagram of the Possible Fates of Materials Introduced into the Waters of a Receiver System by the Waters of a Donor System.</u>

While our model cannot be viewed as a quantitative model, it is nevertheless a useful qualitative model with which to begin making predictions as to changes in water quality brought about by the proposed diversions as required by this study.

Several major points must be borne in mind as we expand our discussion on water quality. First, there are dozens of physical, chemical, and biological parameters to consider. Second, we have four hydrologic phases for the entire project to consider, extending from the year 1972 to 2000. Finally, the relative proportions of Ware River, Connecticut River, Tully River and Quabbin watershed waters will vary over this period of years. This discussion will focus on changes in water quality as a result of the proposed diversions. Attempts will be made to restrict the discussion to the more important issues; no attempt is made to discuss all parameters.

Northfield Mountain Diversion

Diversion of Connecticut River water into Quabbin Reservoir in 1976 will initially increase the turbidity of the reservoir water. The final turbidity will depend upon mainly (1) fallout of some material in Connecticut River water to the sediment after diversion, (2) the relative dilution of Connecticut River water by ambient Quabbin volume, (3) transformations of materials, (4) the influence of ionic strength changes, and (5) the influence on pH changes. Based on only preliminary data, the fallout of material could be significant after a residence time of 60-90 days. The dilution, however, can never exceed a factor of about 5 to 10 depending upon what volumes and how much mixing one considers. Also, water originating in the Connecticut River will be between 18 and 19% of the volume of the entire reservoir during the period 1980 to about 2000 (Table 4). Transformations may change the molecules or colloidal aggregates but will not necessarily cause an elimination. Finally, Connecticut River water will undergo a drop in specific conductance after it enters Quabbin; this will tend to stabilize the colloidal suspensions. If we assume that the Connecticut River will have an average turbidity of less than 25 during freshet flow and that extremely high values are possible but infrequent occurrences, all factors considered above will tend to bring the final turbidity down to a lower value. While we cannot predict what this value will be, it will probably vary between 0.5 (present turbidity) and about 2. Thus, it may not meet future U. S. Public Health Service Standards for drinking water. The turbidity will probably not rise as much during the first two diversion cycles (years 1976-1978) because of the smaller relative proportion of total water originating in the Connecticut River (Table 4). After the Tully diversion begins in 1980, the turbidity will be stabilized at the then current value, since the turbidity of the Tully system is less, and the percentage of Connecticut River water in the reservoir volume will remain approximately constant (Table 4).

Ions that form insoluble complexes (Mn, Fe, Ca) tend to precipitate out into the sediment if suitable anions are available. Such anions decrease in concentration as the pH becomes more acid, and thus these ions will tend not to precipitate out as the Connecticut River waters mix with Quabbin waters. On the other hand, these ions originating from Tully River waters will tend to precipitate out as the more alkaline conditions of the Quabbin Reservoir are encountered. Thus there is a tendency to balance. However, it cannot be predicted what the trend will be over a two-decade period, because the exact proportions cannot be predicted and the long-range stability for pH values in all systems is unknown.

There are at least two major concerns on the possible deterioration of water quality that have ecological significance. One concerns oxygen depletion, and the other is the introduction of additional nutrients which can lead to eutrophication.

A comparison of study data with other available data suggests that COD values for the Connecticut River are about two times as high as for the Quabbin "inside" stations, and are somewhat greater than twice the values for the Quabbin "outside" stations. Reference to known data for the past decade shows occasional COD values for the Connecticut River above 50 mg/l. Both the Connecticut River and Quabbin Reservoir waters maintain high O_2 levels, and during the freshet-flow periods are probably close to saturation. The concern here is an assessment of the potential depletion of O_2 from Quabbin waters as a result of the proposed diversion.

COD represents a potential O_2 consumption that is measured using a strong chemical oxidizing agent. Such potential oxidation may never be achieved under field conditions, where biological processes mediate the chemical reactions. Actual oxygen consumption is a function, in part, of the kind of materials that are included in the COD measurement.

Organic materials may represent a major portion of the COD when COD's are high and usually exert an oxygen demand through biological processes. Although these organics are all oxidized in measuring COD, some, such as simple sugars, are easily oxidized through biological processes, while others such as cellulose (a sugar polymer) are relatively resistant to biological oxidation. Depending on the ease with which the material can be oxidized under natural conditions, the full COD may or may not be exerted upon the water.

If the most of the COD is in particulate form (which is probably true for the Connecticut River) much of the material with a potential demand for oxygen could settle out either in the Northfield Pumped Storage Reservoir or in upper Quabbin Reservoir after diversion. Although settling reduces the COD of the water column, the potential oxygen demand is conserved in the mud. Moreover, the organic component of the sediment may be acted upon by the lacustrine microbial populations at the mud-water interface, and transformed into more easily oxidized compounds. Some materials in the diverted waters may interfere with biological activity in the mud-water interface and either inhibit or enhance the transformation processes. Seasonal turnover and wind effects can stir up these bottom deposits into the water column. These effects are intensified if the reservoir levels decrease. The resuspension of transformed organic muds can serve to deplete available oxygen quickly because COD that had accumulated over many years through the settling process is suddenly present in the water column. If the stirring of the bottom mud never occurs, then COD that is settled out may be buried in the anaerobic sector of the mud and may never exert its O_2 demand on the water.

Included in COD values are the oxygen demands of inorganic materials such as iron and manganese. These inorganic forms can have high O_2 demands if they are in a chemically reduced state. However, in the Connecticut River, laboratory analysis shows that the iron is mainly Fe_3 and that the manganese may also be already oxidized.

All the above factors make it difficult to predict the impact of diverting Connecticut River waters with a higher COD into Quabbin Reservoir. Localized oxygen-depletion effects have been observed in the eastern arm of the reservoir. It is probable that similar effects will be observed after diversion in the northern part of the reservoir as well. The impact on the hypolimnion in the deeper part of the reservoir cannot be predicted at this time. Diversion of waters from the Tully system will probably cause relatively less impact, since the COD values are lower. However, this depends on the specific molecules which comprise the COD and comparisons based on COD values alone must be tentative. Oxygen depletion will depend on a complex of biological and chemical processes in these aquatic systems. In conclusion, then, it is very possible that the proposed diversions may result in some localized oxygen depletions in the reservoir. The extent and magnitudes of such depletions cannot be predicted.

The changes in water quality resulting from nutrients introduced from the diversions must also be assessed. Most experts agree that C, N, P and trace materials are important nutrients for algal growth.

However, significant levels of C, N, and P already exist in Quabbin, especially in the general area of the proposed diversion discharge. Connecticut and Tully Rivers have higher values for N and P in general than Quabbin, but not by large factors. Nutrients are discussed further in subsequent sections. Their importance as far as water quality is concerned lies in the potential for eutrophication.

The presence of phenolic compounds warrants some discussion. Phenols were reported in four riverine stations in the northern tributaries of the Millers River in concentrations in the order of 1-10 ppb. This is considered an undesirable level for drinking water (FWPCA, 1968). However, several factors must be considered here. First, no odors were detected and secondly, in a spot check the presence of lignins and tannins was found in these waters. When the detection method is not sensitive enough, as in this case, it is possible to get a positive indication from any phenolic substances. Also, these test results were taken after an extensive growth of vegetation, and when color in the water was also high. It is very probable, then, that the phenols reported may not have been simple phenolic materials, but the presence of phenolic groups on more complex molecules.

Referring back to the model (Figure 2), a number of mechanisms can be expected to operate after the diversions of river water. Much of the larger material will settle out, probably within hours and days. Many transformations can be expected, based on both inorganic and biological reactions. Detergents would be degraded, although no significant MBAS levels were found. As the carbonates from the Connecticut

River reach the more acid reservoir waters, equilibria will shift and some CO_2 will go off to the atmosphere. Those from the Tully would be retained. However, they are relatively low. Organic materials including the CCE will probably be oxidized. Some NH_3 may also be oxidized, but most of it would be transformed by the biota. Color would decrease. This loss of color could be at least tenfold, based on evidence from the existing Ware River diversion. Finally, many highly insoluble organic materials, including hydrocarbon pesticides and organomercury compounds would tend to evaporate, as they reach the relatively large surface area of the reservoir.

The general trend will be towards the improvement in quality as the diverted water is retained in the reservoir. Whether the retention time of 60 to 90 days before the Connecticut River and Tully system waters reach the general position near Shaft 12 is sufficient to cause recovery ($\Delta QR = \Delta QL$) is unknown. However, the much longer retention times to reach the Winsor Dam area could also allow for some recovery. It is assumed that dilution with ambient reservoir volume will not restore the water quality alone. Some "fallout" of materials due to sedimentation, transformation and evaporation must occur to restore quality. The "treatment plant" capacity of the reservoir can probably handle some restoration of water quality. The magnitude of this capacity is now unknown. Because of its capacity to handle waters from the Ware River diversion with efficiency for 30 years of diversion, we may assume it has some reserve capacity. However, assuming that a loss of water quality occurs with some diversions of Connecticut River water, further deterioration will be checked as Phase III begins.

Several general statements appear useful at this point to tie together the analysis. During Phase I the water quality will deteriorate as the volume in Quabbin Reservoir decreases. This loss of quality could progress to a dangerous point if the volume of hypolimnion waters is drastically reduced. Any losses in quality due to Connecticut River diversion must be judged in the light of water quality loss without diversion. Secondly, the volumes of water represented by Connecticut River origin will be relatively low during the first few diversions. This allows ample time to study the actual impact of diversion during a period of lower potential to cause a negative impact on water quality. Thirdly, the Tully system diversion in increasing total volume (Phase III) should improve the "treatment plant" capacity of the reservoir and thus an improvement in quality may take place. Also, it must be remembered that as the pollution abatement plans are implemented in the 1970's, the quality of riverine waters will improve. Finally, without even further sources of water inflow, Quabbin Reservoir is destined to deteriorate rapidly by the end of the century, because low water levels will interfere with natural treatment processes.

Donor Systems

Turning now to the donor systems, diversion of water from any stream or river, which is receiving inputs of nutrients or pollutants downstream from the diversion site, will have the effect of increasing the concentration of the nutrient or pollutant above what it would have been without the diversion. Berger (1971) has pointed out that the reach of the Connecticut River between Northfield, Massachusetts and Thompsonville, Connecticut receives a disproportionate load of nitrogen and phosphorus. The effect of the proposed diversions would be to increase the concentration of these additional nutrients by 3% at most. Considering, for example, that flood flows now have a 50% lower concentration of both nutrients than do low flows at Thompsonville, the projected increases would not be significant. Indeed, they would be less than normal annual fluctuations in the water.

On similar grounds, other water quality parameters would not change to any significant degree. One might argue that slight reduction in flow volume will reduce the total mechanical erosion of the banks and thus reduce the solid load and turbidity downstream. We view these changes of a few percent, however, to be insignificant, and to leave neither positive nor negative impacts on water quality below the proposed diversion site on the Connecticut River. We add, however, the possibility that retention of Connecticut River water in the upper reservoir of the Northfield pumped storage facility may cause some changes in water quality. However, the impact of these changes in water quality will probably be minor, after the water is returned to the Connecticut River.

Because of the complex of impoundments and the larger relative volumes proposed to be diverted, the impacts on the Millers River system are potentially greater. Diversion from Priest and Tarbell Brooks would decrease the water quality on the Millers River under present conditions during days of diversion, especially at South Royalston. Diversions from other locations of the Tully System would increase even further any losses in water quality along the mainstem of the Millers River.

During the spring runoff period, paper pulp in suspension was noted at South Royalston and at decreasing concentrations at all other Millers River stations. Apparently, the turbulence associated with high flows would tend to reduce the effectiveness of this cleansing action. However, apparently the existing uncontrolled flows are not adequate to clean the river. It is necessary to stop the input of pulp before this suspended load can be reduced. After the proposed state-federal secondary treatment cleanup of the Millers River, the diversion during spring runoff periods would have only minimal impacts on water quality downstream to the Connecticut River. Thus the short term impact of the proposed diversion will be to decrease water quality downstream, but because of the proposed cleanup, long term impacts should be minimal.

Impoundments present other problems. Shallow ponds, such as those proposed for the tributary streams, tend to reduce the quality of water impounded in them. Water temperatures are increased, algal populations tend to bloom, and dissolved oxygen depletions occur as the algae blooms decline. The short-term outlook for water quality in the impoundments, is a decline in quality. The long-term (20 year) projection is definitely toward lower water quality from the impoundment areas.

In general, the longer the retention time, the greater the probability of ecological changes towards the lentic condition. Although specific changes in the ecology of a single impoundment are difficult to predict, it is reasonable to assume that the ecological changes in the impoundments at Tarbell Brook and the West Branch of the Tully River will progress more closely towards a relatively stable lentic condition than will those at Priest Brook, for example. Thus we visualize a whole range of ecological changes in the impoundments.

Impacts on Ecology

There can be little doubt that increased levels of nutrient chemicals will be detected in Quabbin Reservoir after the implementation of the Tully system diversion. However, not all nutrients can be expected to show such an increase in this time period. Phosphorus increases are possible, but not probable. Increases in available carbon, on the other hand, are quite probable, if only due to the relatively high alkalinity of the Connecticut River. Also, the fact that fecal contamination of the Connecticut River does occur increases the likelihood that complex organic molecules will be introduced into Quabbin and possibly into Wachusett where they will become part of the nutrient pool. The future abatement of pollution in the Connecticut River will contribute significantly to the lowering of any such nutrient addition to the reservoir through diversion.

Specific studies showed no significant probable impacts on the general ecology of the mainstem Connecticut River as a result of the proposed diversions. Losses in flow volume and shifts in water quality will be so minor that it is difficult to envision any significant changes in bacterial, algal and benthic populations. Similarly, no major changes in the existing fish populations, or in the future anadromous fish program are expected.

General predictions were made on the impacts of the proposed diversions on Quabbin Reservoir. Potential impacts have both public health and general environmental significance. Dilution of riverine waters by ambient reservoir volume alone will probably not be sufficient to insure an acceptable water quality in Quabbin Reservoir. Fall out of suspended materials and the "treatment plant" capacity of Quabbin Reservoir are expected to produce water of an acceptable quality.

Phase II (1976-1980), the period when the Connecticut River water is entering Quabbin before the implementation of the Tully system, appears to contain the most potential for ecological and public health impacts on Quabbin Reservoir. Phase III (1980-1989) will probably be associated with general improvement in water quality. Phase I (1972-1976) and Phase IV (1989-2000) will show some deterioration of water quality caused by declining reservoir volumes.

Specific impacts on the ecology of the Millers River system are probable. The impoundment of waters from the northern tributaries will cause changes in the algal and heterotrophic bacterial populations. While the probability that these changes will occur is good, the details cannot be predicted. Eutrophication and algal blooms will increase over the years, and thus offer a long term (over 20 years) impact.

Changes in benthic populations in the mainstem Millers River will be slight, except for a possible increase in the benthic fauna characteristic of poor quality water at Station No. 4 (South Royalston). This, however, will be a short term impact, and will reverse itself after the Millers River is cleaned up under the proposed state-federal abatement plans. The impoundments will result in gradual changes in both benthic fauna and fish populations, as they change from lotic to lentic environments. These changes will be influenced by drawdown and other dynamic changes in the hydrology. Tributaries will experience minor changes in general ecology. Consistent with previous statements, changes in the ecology in impoundments are more probable in Tarbell Brook and the West Branch of the Tully.

Finally, little detailed information on the construction phase of the proposed diversions has been available for study. Therefore, the impact of this phase on donor and receiver systems cannot be discussed in this report. However, both the MDC and the Corps of Engineers are well aware of the importance of this phase to any understanding of the overall environmental impact of the proposed diversions.

Connecticut River Estuary Study

At the initiation of the planning process it was apparent that biological attention would have to be given to the estuary. Preliminary thinking was that at certain rates of diversion perhaps the lessening fresh water inflow into the estuary could physically move the salt/fresh interface from its historic position to another location. Such a change, coupled with a temperature rise, could effect the organisms which call the estuary home as well as those species which pass through the estuary on their spawning run. These and other considerations led to the development of a study "to predict the probable impact of upstream freshwater diversion, during spring freshet periods, on the salinity-temperature regimen of the Connecticut River Estuary and to further correlate these changes with possible effects on the biotic community of the estuary." The contract required that the effects of diversions at Northfield, Massachusetts of 600, 800, 1000, 1600, 2000, 3000, and 4000 cubic feet per second be tested in each of two cases: first, when the average daily discharge at the United States Geological Survey's gaging station at Montague City, Massachusetts is 12,000 cubic feet per second or above, and second, at an average daily discharge at Montague City of 17,000 cubic feet per second or above. These discharges (i.e. 12,000 and 17,000 cfs) are being considered as alternative rates below which no diversion will take place, and are referred to as control flows. For the purposes of this study the Connecticut River Estuary was defined as that part of the Connecticut River lying below the Enfield Dam. Spring freshet is defined as that period in the spring of the year during which no upstream flow is recorded at the United States Geological Survey's gaging station at Bodkin Rock, near Middletown, Connecticut.

Summary of Study Conclusions

1. Changes in river temperature due to the diversions under consideration should not exceed 0.61°F under the worst case postulated (i.e. 12,000 cfs at Montague City and 4,000 cfs diversion). Although many biological effects of temperature elevations are well known, in most cases the effects resulting from such a small temperature increment are too small to quantify.

Biological evaluations were made using a 2°F temperature rise in the estuary. The rationale for choosing this temperature rise is twofold. First, biological changes could not be predicted on much less than a 2°F increment of change and secondly, it would be only an academic exercise to try to refine predictions at a smaller increment of change if in fact no significant changes would occur at the 2°F increment. As it turns out, even a 2°F temperature rise would not cause a serious impediment to presently considered diversion plans as far as the ecological balance of the estuary is concerned. Keeping in mind that the calculated temperature rise is less than 1/3 the value used in biological evaluation (.61°F vs. 2°F), the reader is advised of the conservative nature of the biological evaluation that is presented in this statement and discussed in the following paragraphs.

Among the known biological effects of increased temperature, the following may be expected, but it should be kept in mind that even if deleterious, the small change in temperature will result in too small a magnitude of change to be cause for alarm.

a) Change in the Time and Location of Shad Spawning

Studies have indicated that the ovaries of female shad develop slowly when exposed to temperatures of 55 to 65°F and more rapidly when exposed to the warmer temperatures of 68 to 77°F. This apparently means that shad will tend to hold their eggs longer and migrate further up-river during a cold water spring. This is borne out by observations during May 1967, when cooler than normal temeratures caused spawning to take place in the upper reaches of the study area. In contrast, the warmer temperatures of May 1968 caused spawning to occur further downstream.

Calculations indicate that a 2°F temperature rise in the river water would have caused spawning to occur 3.4 days earlier in 1967 and 3.6 days earlier in 1968. It is postulated that the most severe diversions postulated would have an insignificant effect on shad spawning.

b) Shad Egg Size, Abundance, Development Time, and Mortality

Calculations indicate that a 2°F temperature rise would reduce average egg size from 3.06 mm to 2.84 mm. This decrease is considered insignificant since it falls well within the normal range of egg sizes (2.1 to 3.1 mm). Available data does not lend itself to a correlation of egg abundance to temperature or flow.

A definite correlation between egg development time and water temperature has been observed; however, a 2°F temperature rise is expected to cause eggs to develop only 17 hours earlier. This would still put the average development time well within the naturally occurring limits of development time. High water conditions and widely fluctuating temperatures are considered the chief cause of egg mortality and since diversion will not worsen either of these conditions, no increased egg mortality is expected.

Shad spawning success in general will not be greatly influenced by the postulated diversions. After diversion, temperatures would still remain well within normally occurring variations and since spwaning occurs well above the salinity intrusion, any changes in salinity patterns will not affect spawning.

c) Effects on Survival of Eggs and Larvae of Shad and Resident Fish Species

Temperature rise and salinity changes that would be brought about by the postulated diversions are not expected to affect eggs and larvae survival, development or growth of any of the fish species tested.

d) Adult Fish Populations

Massive blueback herring kills were reported in 1965 to 1967, however, these occurred during the summer months as dissolved oxygen fell below 4.3 mg/1 and temperatures rose above 77°F. Since these conditions occurred well beyond the period of contemplated diversion, no worsening of an already bad situation is to be expected. Some adult fish could feel an effect of the diversion as a result of shifting (in time) of the availability of a food supply. Food generally becomes available as temperatures exceed 40°F. A 2°F temperature rise would have caused this 40°F temperature to be reached 4.3 and 6.8 days earlier in 1969 and 1970 respectively. Since some adult fish winter in coves and do not move out into the river until temperatures reach $40^{o}F$ in the coves, they may arrive in the river up to a week after the food supply begins to develop. This assumes that water temperature in the coves would not be influenced by the $2^{o}F$ temperature rise in the river. More information is needed in this area to draw any definite conclusions, but no problem of significant proportions is anticipated.

e) Homing Ability and Timing of Arrival of Adult Shad

Adult shad appear to be able to home even during extreme low flows. Diversion will not reduce flows during these extreme low flow conditions so it is logical to assume that the shad's homing will not be impaired by diversion of freshet water. Historically it has been found that shad tend to enter the estuary when temperatures reach 40^{o} to $43^{o}F$. Diversion would cause these temperatures to be reached somewhat earlier, but no problem is anticipated.

f) Microbiological Population

Because of the paucity of data in some critical areas of basic biology deemed pertinent considering the postulated diversions, no absolute predictions can be made regarding the ultimate fate of microorganisms in the estuary. Since the temperature and salinity rises are so small ($72^{o}F$ and a few Mg/L) at any given point and since these changes develop over a period of time, no significant qualitative or quantitative alterations of bacterial populations are to be expected in the short run (a few years). Beyond this span any prediction would be speculative.

g) Invertebrates

Forty Eight recurring species of invertebrates have been identified in 60 months of sampling. Of these, four species are dominant. In their order of abundance are Limnodrilus hoffmeisteri, a worm; Psectrotanypus and Cryptochironomus, flies; and Pisidium, the fingernail clam. A 2°F temperature increase can be expected to increase the metabolic activity and probably advance sexual maturity slightly in each of the above species. However, since the postulated diversions will not be made during summer low-flow-high-temperature situations, these species are not put under any undue stress. Temperatures after postulated diversion will still be well within the limits of naturally occurring variation and only minimal adverse effects are to be expected.

2. Freshet conditions should continue throughout the estuary if no diversion takes place when flows are less than 17,000 cfs at Montague City. The duration of freshet will be shortened by 2 to 4 days at both the onset and cessation of freshet in a normal year with diversion. If 12,000 cfs were considered as a control flow, then freshet conditions would be shortened by 3 to 9 days at both the onset and cessation of freshet in a normal year.

3. At a 12,000 cfs controlling flow at Montague City, minor reversals of current may occur in the lower estuary. These should not be sufficient to cause a biologically significant intrusion of saltwater from Long Island Sound.

4. Under either controlling flow regime, changes in salinity distribution will be too small to have measurable biological effects.

To give the reader insight on how and why these conclusions were reached, the following three sections on temperature, freshet conditions, and salinity, are taken directly from the original report as illustrative of the analysis of data and approach used in reaching the foregoing conclusions.

Effects of Diversion on Temperature Regimen

In order to calculate the changes in temperature caused by varying diversions, the following assumptions are necessary:

1. The presently existing heat load will remain unchanged.

2. Complete mixing of heated effluents occurs within a reasonable distance from the outfalls.

3. There is no significant gain or loss of heat from the water to either earth or air.

The first assumption is clearly unreasonable in a light of existing plans and projections for expansion of steam generating capacity and other processes requiring large amounts of cooling water. As such additional sources of heat materialize, their effects on the temperature regimen should be studied in relation to the various diversions.

The second assumption is borne out by previous work on warm water effluents. It has been shown that the warm water effluent from the Connecticut Yankee Atomic plant becomes thoroughly mixed with the confluent river water within approximately two miles of the outfall at most seasons of the year. Infrared thermometry shows highly localized temperature peaks in the vicinity of other thermal effluents, indicating that they too mix within a relatively short distance. Furthermore, since the diversions are to be limited to freshet conditions, mixing will be aided by the high velocities and turbulence which are characteristic of freshet flow. Indeed, during freshet conditions the thermal structures associated with the Connecticut Yankee Atomic Plant outfall are found to disappear.

The third assumption seems reasonable, at least during the freshet season, since during this period of the year a net rise in temperature occurs. Heat losses to the earth are minimal inasmuch as the temperature differential between earth and water is at or near its annual minimum at the onset of freshet, and does not increase greatly by the end of freshet.

With one exception, the heat inputs used for the mixing calculation are in accordance with values supplied by the Corps of Engineers. In the case of the Connecticut Yankee Atomic Plant the values have been adjusted from an effluent rate of 814 cubic feet per second with a temperature rise of 20.4°F as stated by the Corps of Engineers to an effluent rate of 830 cfs and a temperature rise of 22.8°F in accordance with more current information (Merriman et al, 1970). These data, and the thermal load resulting from the described effluents are presented in Table 5. The thermal loading from the Vermont Yankee Atomic Power Company's plant at Vernon, Vermont is not included in these calculations, since it is above the point of diversion, and the anticipated load from this source would not change the conclusions of this study.

Table 5

EXISTING THERMAL LOAD

SOURCE	EFFLUENT RATE (CFS)	TEMP. RISE (F.)	LB./SEC	BTU/SEC	
Above Enfield					
Mount Tom	201	11.8	12,542	147,996	
Riverside	66.5	11.8	4,150	48,970	
Holyoke	41	12.0	2,558	30,696	
W. Springfield	249	16.1	15,538	250,162	
State Street	80	11.8	4,992	58,906	
S. Meadow	523	10.4	32,635	339,404	876,134
Estuary					
Maromas	570	13.0	35,568	462,384	
CYAP	830	22.8	51,792	1,180,858	1,643.242
			TOTAL		2,519,376

Inasmuch as there are two large heat sources located near the middle of the Connecticut River Estuary, the mixing calculation has been divided so as to cover the upper reach of the estuary, above Maromas, and the lower reach of the estuary, below the Connecticut Yankee Atomic Plant. Discharges at Thompsonville and Bodkin Rock are calculated from the given discharges at Montague City by means of mathematical relationships. For the upper estuary temperature elevation calculation, Thompsonville discharges are used, while the lower estuary values are based upon Bodkin Rock calculated discharges. Results of these calculations are given in Table 6. Certain minor thermal loads have been ignored, largely because of the near impossibility of obtaining accurate data, but also because of their extremely small magnitude. No attempt has been made to account for any difference in solar heating as a result of the various diversions, since specific data for the Connecticut River are not available. A theoretical approach could be used to indicate the magnitude of such changes, however at the presently postulated levels of diversion it is not believed that the results would be of any great significance. In the event that larger diversions are proposed at any time, or if diversions are proposed which will reduce the minimum flow at Montague City below the presently postulated 12,000 cfs, such studies should be pursued.

River temperatures have been monitored at five stations in the vicinity of the Connecticut Yankee Atomic Plant for approximately six years, as part of a long term study to assess the effects of this plant on the Connecticut River. Figure 4 gives the locations of these stations. Monthly high, mean and low temperature for the period from

Table 6

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TWO REACH MIXING CALCULATION

TEMPERATURE ELEVATIONS (DEG. F.) ABOVE MAROMAS (UPPER VALUE) AND BELOW CYAP (LOWER VALUE). FOR STATED DIVERSIONS AT NORTHFIELD. HEAT LOADS BASED ON USACE MEMO NO. 3. FLOWS CALCULATED BY LINEAR REGRESSION EQUATIONS.

FLOW AT MONT-AGUE CITY	CALCULATED FLOWS AT THOMPSONVILLE	CALCULATED FLOWS AT BODKIN ROCK	DIVERSIONS AT NORTHFIELD (CFS) 0	600	800	1000	1600	2000	3000	4000
100000.	115049.	129843.	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13
			0.31	0.31	0.31	0.31	0.31	0.32	0.32	0.32
90000.	103552.	116741.	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
			0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.36
80000.	92054.	103639.	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16
			0.39	0.39	0.39	0.39	0.40	0.40	0.40	0.41
70000.	80557.	90538.	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18
			0.45	0.45	0.45	0.45	0.45	0.46	0.46	0.47
60000.	69059.	77436.	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.22
			0.52	0.53	0.53	0.53	0.53	0.54	0.54	0.55
50000.	57561.	64334.	0.24	0.25	0.25	0.25	0.25	0.25	0.26	0.26
			0.63	0.63	0.64	0.64	0.64	0.65	0.66	0.67
40000.	46064.	51233.	0.30	0.31	0.31	0.31	0.32	0.32	0.33	0.33
			0.79	0.80	0.80	0.80	0.81	0.82	0.84	0.85
30000.	34566.	38131.	0.41	0.41	0.42	0.42	0.43	0.43	0.44	0.46
			1.06	1.08	1.08	1.09	1.11	1.12	1.15	1.18
20000.	23069.	25029.	0.61	0.62	0.63	0.64	0.65	0.67	0.70	0.74
			1.61	1.65	1.67	1.68	1.72	1.75	1.83	1.92
19000.	21919.	23719.	0.64	0.66	0.66	0.67	0.69	0.70	0.74	0.78
			1.70	1.75	1.76	1.78	1.83	1.86	1.95	2.05
18000.	20769.	22409.	0.68	0.70	0.70	0.71	0.73	0.75	0.79	0.84
			1.80	1.85	1.87	1.89	1.94	1.98	2.08	2.19
17000.	19619.	21099.	0.72	0.74	0.75	0.75	0.78	0.80	0.84	0.90
			1.91	1.97	1.99	2.01	2.07	2.11	2.23	2.36
16000.	18469.	19789.	0.76	0.79	0.79	0.80	0.83	0.85	0.91	0.97
			2.04	2.10	2.13	2.15	2.22	2.27	2.40	2.56
15000.	17320.	18478.	0.81	0.84	0.85	0.86	0.89	0.92	0.98	1.05
			2.18	2.26	2.28	2.31	2.39	2.45	2.61	2.79
14000.	16170.	17168.	0.87	0.90	0.91	0.93	0.96	0.99	1.07	1.15
			2.35	2.44	2.47	2.50	2.59	2.66	2.85	3.07
13000.	15020.	15858.	0.93	0.97	0.99	1.00	1.05	1.08	1.17	1.27
			2.55	2.65	2.68	2.72	2.83	2.91	3.14	3.40
12000.	13870.	14548.	1.01	1.06	1.07	1.09	1.14	1.18	1.29	1.42
			2.78	2.89	2.94	2.98	3.12	3.22	3.50	3.83

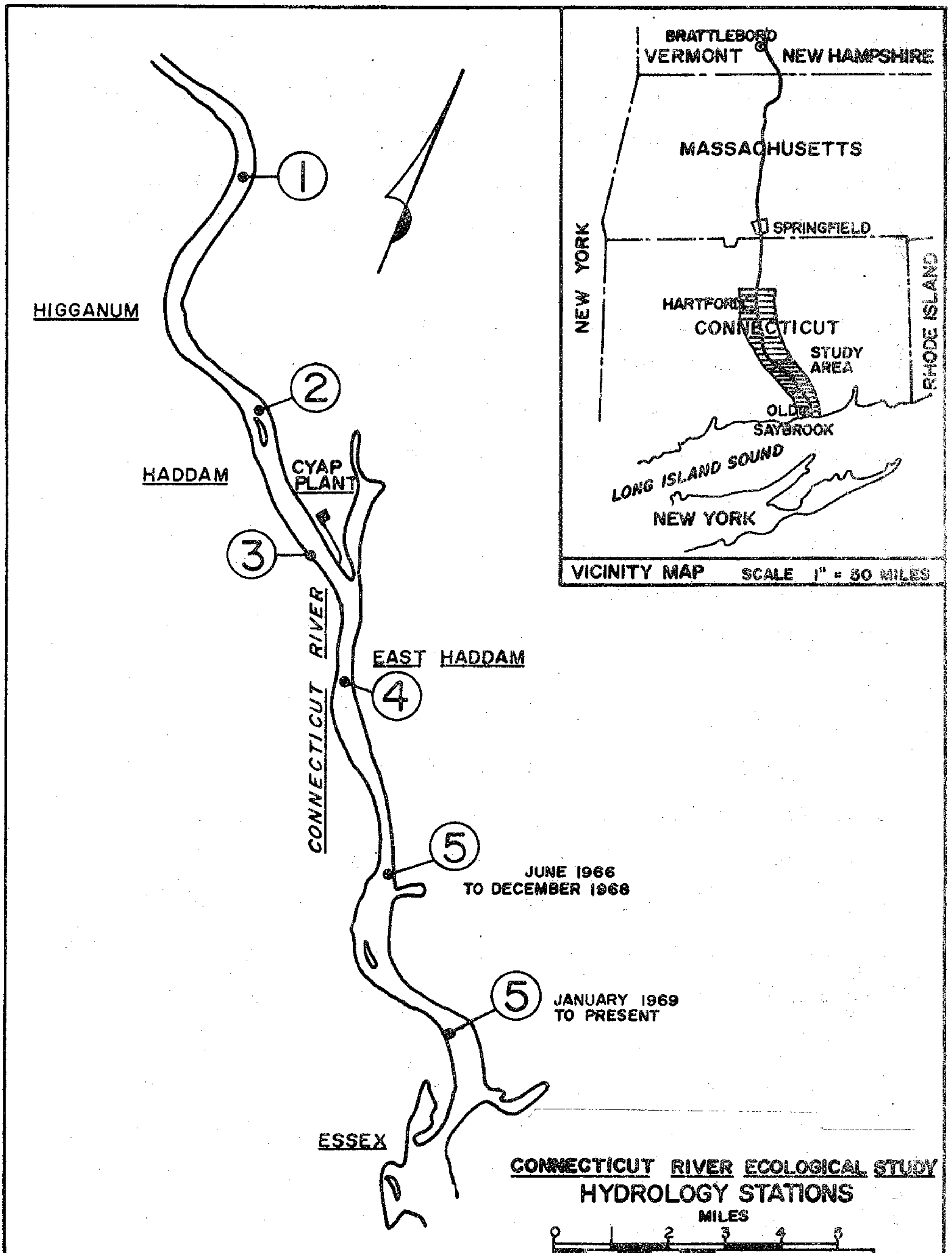

BRATTLEBORO
VERMONT
NEW HAMPSHIRE
MASSACHUSETTS
SPRINGFIELD
NEW YORK
HARTFORD
CONNECTICUT
STUDY AREA
RHODE ISLAND
OLD SAYBROOK
LONG ISLAND SOUND
NEW YORK
VICINITY MAP SCALE 1" = 50 MILES
HIGGANUM
HADDAM
CYAP PLANT
CONNECTICUT RIVER
EAST HADDAM
JUNE 1966 TO DECEMBER 1968
JANUARY 1969 TO PRESENT
ESSEX
CONNECTICUT RIVER ECOLOGICAL STUDY
HYDROLOGY STATIONS
MILES
0 1 2 3 4 5
0 5000 10000
YARDS

Figure 4

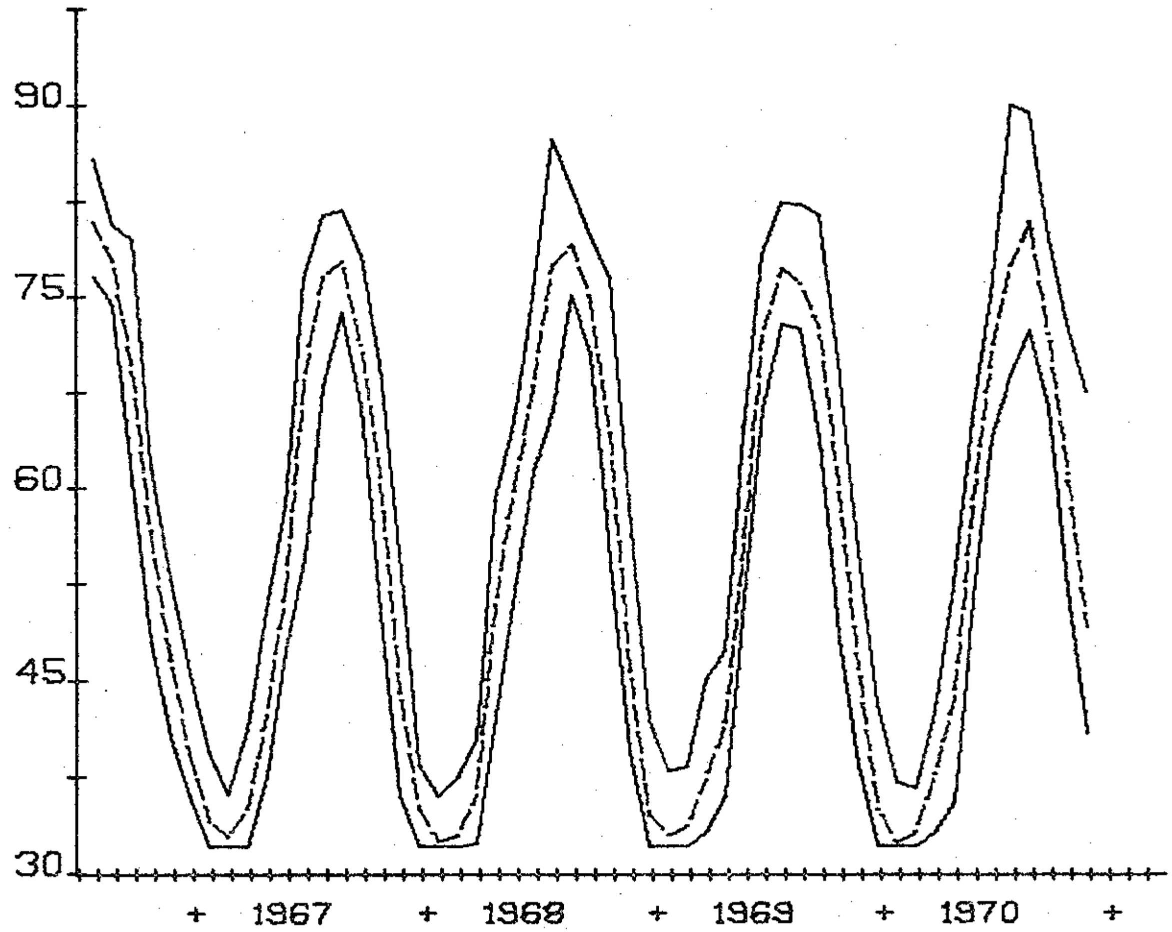
July 1966 through November 1970 have been taken from the data gathered for this study, and are presented in Figures 5 and 6 for Stations 3 and 5 respectively. The breaks in these plots represent periods in which the monitoring stations were removed because of heavy river ice.

Effects of Diversions on Freshet Conditions

Freshet, as defined for the purposes of this study, occurs at Bodkin Rock when a discharge of approximately 22,000 cfs is attained, and persists until the discharge falls somewhat below this rate. 22,000 cfs at Bodkin Rock is equivalent to 17,698 cfs at Montague City, so it is apparent that diversions at Northfield which do not reduce Montague City discharges below 17,000 cubic feet per second will not prevent freshet conditions in the lower estuary. On the other hand, flows of 12,000 cfs at Montague City, equivalent to only 14,549 cfs at Bodkin Rock would not produce freshet flows at this level.

USGS flow records for Bodkin Rock are available for the freshet seasons of 1966, 1967, and 1968. Total discharges during each of the three freshet seasons may be obtained by summing the daily discharges during freshet, as provided by the USGS. These results are presented in Table 6 , with the volumes required for the various levels of diversion expressed both in terms of millions of cubic feet and in terms of per cent of total discharge.

From the foregoing it is clear that maintaining a minimum flow of 12,000 cfs at Montague City will remove freshet conditions in the Connecticut River Estuary as defined for this study, i.e. at Bodkin Rock. This is not to say that freshet will not occur in the upper estuary,



MONTHLY HIGH MEAN AND LOW TEMPERATURES (F) - STATION 3

Figure 5

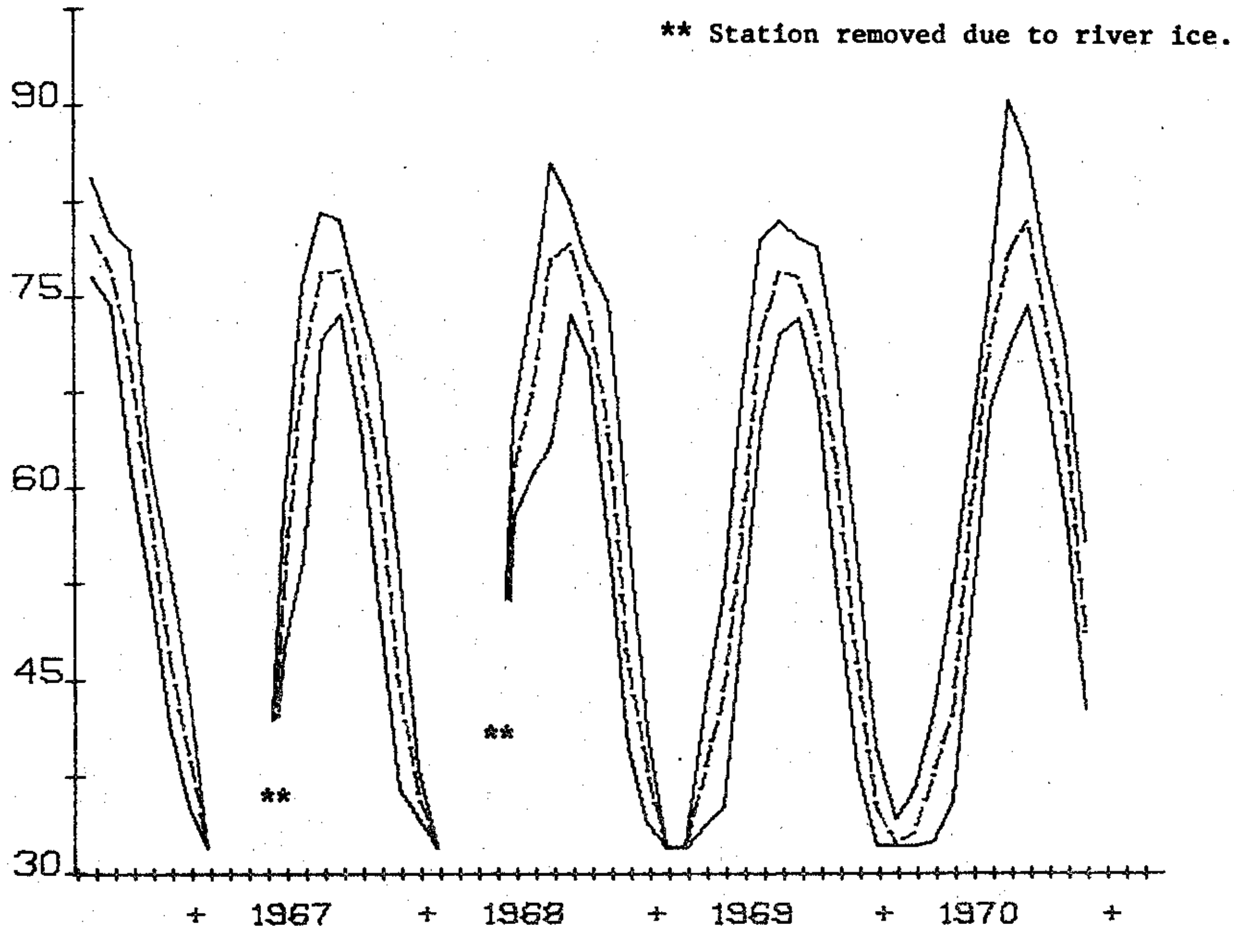


Figure 6

MONTHLY HIGH MEAN AND LOW TEMPERATURES (F) - STATION 5 where tidal effects are minimal and the flows resulting from a minimum discharge at Montague City of 12,000 cfs would be sufficient to produce a continuous discharge.

At a minimum flow of 17,000 cfs at Montague City, it appears that freshet would occur at or very near Bodkin Rock. However, the estuary below Bodkin Rock would undoubtedly experience daily reversals of current, particularly at periods of extreme tides.

As more work is being done on the effects of regulated flows on river morphology, it becomes more and more apparent that small changes in flow often result in large changes in river morphology. It is obvious that the shape and nature of the Connecticut River at any instant is the result of adjustments made over many centuries in response to changing environmental conditions. The annual spring freshet has been an important factor in shaping the river as we know it, and major alterations of these flows, such as diversions beyond the presently postulated limits, will be reflected in changes in the morphology of the river.

Figure 7 portrays daily discharges at Thompsonville for five successive seasons, and shows that both the onset and cessation of freshet are sudden. For this reason, whether the controlling flow is set at either 12,000 or 17,000 cfs, it is unlikely that the postulated diversions will affect the length of the freshet season by more than a few days at either end. While this change may have some biological significance, it seems unlikely that it would have any appreciable effect on the hydrological regimen of the estuary.

CONNECTICUT RIVER DISCHARGE (CFS) AT THOMPSONVILLE

1965 THRU 1970 (DAILY APRIL 1 - JUNE 15)

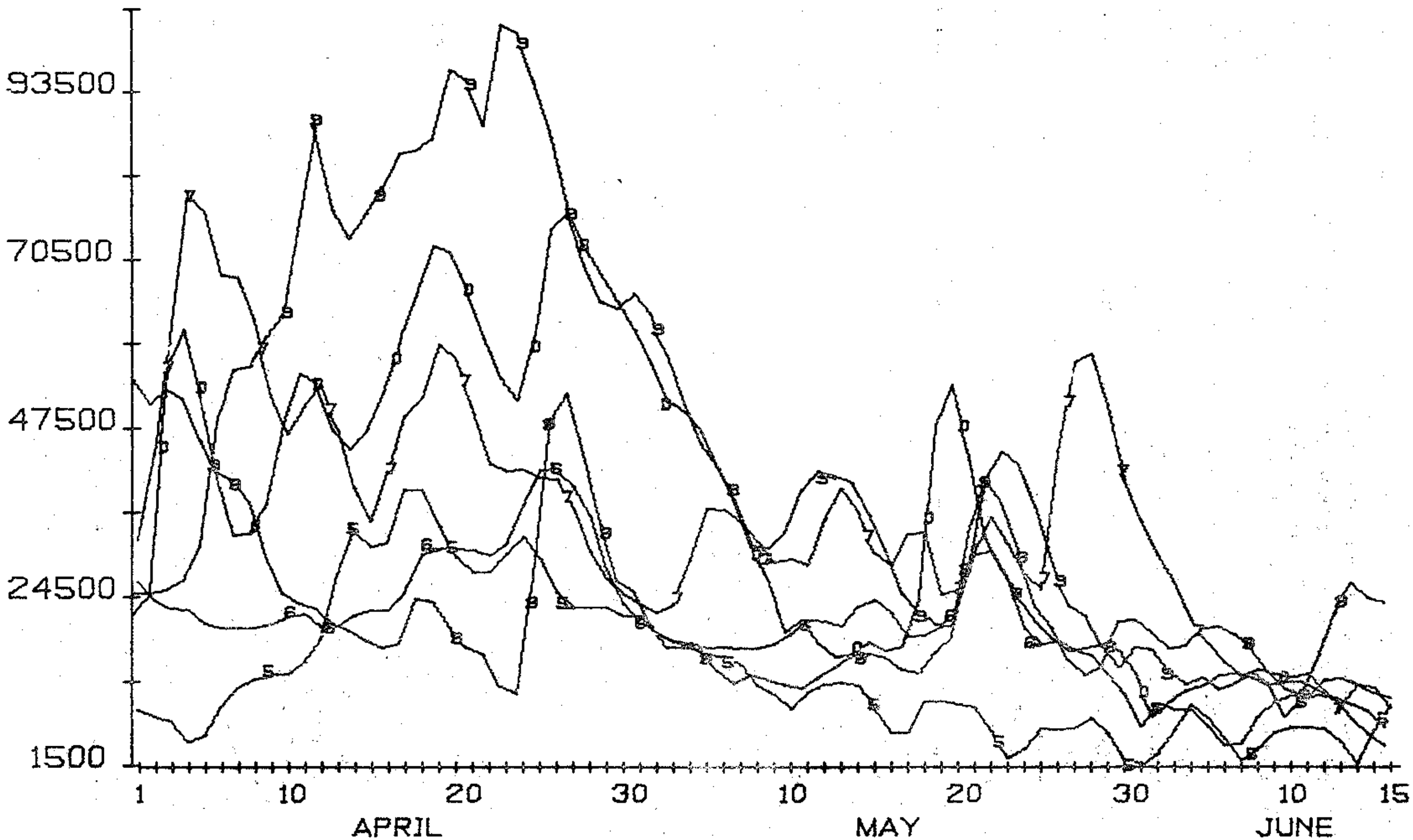


Figure 7

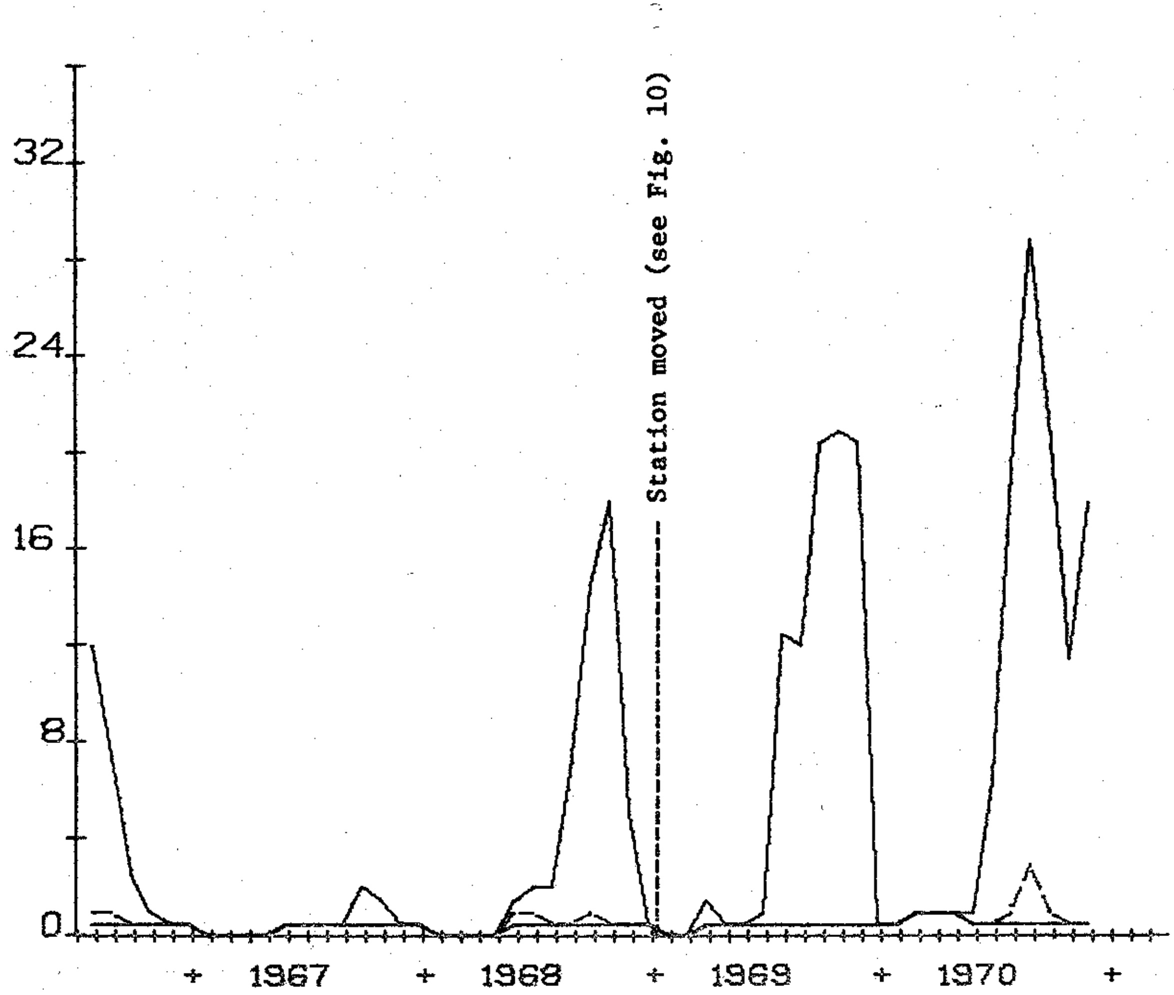
Effects of Diversion on Salinity

Five monitoring stations have recorded conductivity, among other parameters, since July 1966. The purpose of these conductivity measurements is to delineate the movements of the salinity gradient in the vicinity of the Connecticut Yankee Atomic Plant. Monthly high, mean and low conductivity values for Station 5 are given in Figure 8 for the period from July 1966 through November 1970. Station 5 was located on the east bank of the river, 10.3 miles above the mouth until December 1969 when it was relocated to the west bank of the river, 8.0 miles above the mouth. Station 5 was operated seasonally until March 1969, when it was converted to a year-around station.

The results of this work show that the main body of salinity lies below the Haddam Bridge (13.4 miles from the river mouth) for most of the year. Only during seasons of extreme low flow does it approach the Connecticut Yankee Atomic Plant, and then only during periods of extreme tidal ranges. Obviously, during freshet conditions any salinity is restricted to an area within a very short distance from the mouth of the river.

Unfortunately, these stations do not yield any data for that part of the estuary lying within the first eight miles of the river. Meade, however, presents an excellent description of the response of the salinity front to varying rates of discharge. This data are summarized in Table 7 showing the position of various levels of chloride concentrations in terms of their distance from the mouth of the river. Meade also describes the vertical distribution of chlorides, indicating that the gradient steepens with increasing flows, and flattens with decreasing flows.

Figure 8



MONTHLY HIGH MEAN AND LOW CONDUCTIVITY (MMHOS-CM) - STA. 5

Chloride Concentrations near Mouth of Connecticut River

Date	Discharge at Thompsonville (cfs)	Surface Chloride Concentrations (ppm)					
		0.01	1.0	2.0	4.0	8.0	10.0
		Distance (mi.) from Mouth of River					
27 Aug 1935	2,013	12.5	8.3	7.6	5.6	4.0	2.4
29 Sep 1935	5,933	10.7	7.8	7.2	5.4	3.1	-
18 Aug 1935	7,698	9.7	7.4	5.7	4.2	2.0	-
25 Jul 1935	9,322	5.8	-	-	-	-	-
12 Jun 1935	17,798	5.6	-	-	-	-	-
13 Apr 1937	32,030	-	-	-	-	-	-

Meade's work shows that chloride concentrations in excess of one part per thousand did not exist above river mile 2.4 with a discharge at Thompsonville of 17,798 cfs on the preceding day. This indicates that with a control flow of 17,000 cfs at Montague City, equivalent to more than 22,000 cfs at Saybrook, there would be little or no change in the position of the freshwater-to-saltwater gradient. Even with the Thompsonville discharge reduced to 9,322 cfs, Meade shows no concentrations of one part per thousand or more at river mile 5.8. It is obvious that the interface would move upstream with this reduction in flow, but from Meade's work it appears that even at a controlling flow of 12,000 cfs at Montague City, the interface would not move above river mile 5.8.

Providing that freshet conditions are maintained during periods of diversion, saline water will continue to be restricted to the area near the mouth of the river. If diversions are large enough to permit reversals of current in the lower estuary, the salinity front will advance upriver, reaching positions corresponding to the various flows as shown by Meade (1966).

Sediment

At low velocities the silt is undergoing only minor changes; however, during the spring when the velocities are greater than 2 fps the silt is removed from the surface of the sand substrate and carried further downstream. At this time the finer sediment and small organisms are transported until lower velocities occur, in the late spring. Changes occur in the sediment and populations when the water column unloads at these lower velocities. Increases occur especially at the microfaunal levels (protozoans, nematodes, cladocerans, and copepods).

In attempting to assess the effects of diverting 4000 cfs and less during flows about 12,000 cfs no direct association with sediment compositions were found. Based on available information no significant changes in the sediment would occur with a control flow of 12,000 cfs at Montague City.

Conclusions of the Connecticut River Estuary Study

1. Temperature elevations at the highest postulated diversion will be approximately 0.61°F.

2. Maintenance of 17,000 cfs at Montague City will suffice to produce freshet conditions in the estuary - 12,000 cfs will not.

3. If freshet conditions are maintained, there will be no appreciable change in the salinity distribution.

4. If freshet conditions are not maintained, the salinity gradient will migrate in response to changes in discharge rate.

Socio-Economic Impacts of all Diversion Projects

In the evaluation of the socio-economic impacts which any of the diversion projects may have, two conditions were tested. First, if water were made available to meet 1990 needs and second if projects were not constructed. These were called the "go" and "no go" situations respectively. Impacts for both of these situations, that is, "go" or "no go", were then investigated both for communities to be serviced by the diverted water and for those municipalities within the Connecticut River basin. These two sets of communities are referred to in the following paragraphs as receiver and supplier areas, respectively.

For the receiver area, findings can be expressed in two different ways. First, concrete losses with and without diversion can be totalled: all receiver communities with normal runoff conditions and the projects implemented could expect no economic losses. If, on the other hand, projects necessary to meet 1990 needs were not implemented, then these communities could expect losses to total $83 million through 1990. The categories included in those totals encompass industrial, city, emergency city, revenue, commerce, sprinkling, business investment, and domestic investment losses. However, these figures say nothing of the ways in which such losses might be allocated. That is, of the more than $4 million in revenues <u>not</u> collected in 1990 by all receivers under the "no go" situation, there is no way of knowing, for instance, whether it would be municipal expenditures on recreation or on schools or on some other category that might suffer. Therefor, an estimate of the loss in classrooms not built (say 600 rooms) is merely one possible expression of total dollar loss. Similarly, housing units not built are but an alternative manifestation of losses in the private sector.

Under drought conditions, the receiver communities would fare even worse without the diversion projects' implementation. In the event of a drought occurring, concrete losses for the receiver area total over $210 million by 1990.

Social impacts in the receiver area are principally "shadow costs" of concrete losses generated by water shortage. As municipal efforts turn to finding new sources, building bans to hold the line on new demand are a likely eventuality. Second-order effects of expenditures on water searching manifest themselves as slowed school building programs, poorer municipal services (especially fire protection) and a general malaise in the development plans of the subject town. Moreover, it appears that citizens are likely to become discouraged and frustrated as they see their lawns dry up during watering bans. In many ways these feelings are reflected in attitudes about the desirability of their town as a place to live and work. The net result is stagnating growth, hostility toward the communities which snare the industries unable to locate in a water-deprived town, and a growing dependence on M.D.C. admission as the ultimate solution to water shortage.

With respect to the water supply itself, receiver communities benefit from implementation of the diversions in two specific ways. First, exceptionally high water quality and availability will be available to meet future needs. Second, socio-economic losses which would occur without the projects will be avoided at least through 1990.

In general, tangible impacts felt by supplier areas will be related principally to the land taking and subsequent construction activity in any of the communities affected by any of the projects. Royalston is the community affected most significantly, although only by Alternative No. 3, where only 3 percent of its nearly 42 square miles are even potentially exposed to alteration. Evidence of tunnelling to Quabbin from any of the projects will be seen primarily as access shafts in two or three locations and spoil disposal sites which have not yet been finally identified. From an economic standpoint, anticipated changes relate chiefly to the job openings stimulated by construction over a five year period.

Two qualifying points must be made, though, to establish a proper perspective on a labor influx. First, the diversion projects together will require something under 1,000 men -- a comparatively small number with respect to the much larger work forces assembled at Vermont Yankee in nearby Vernon and at Northeast Utilities' pumped storage facility at Northfield. Experience indicates that even if this number were to be larger than in the Vernon case, it is unlikely that the supplier area would suffer any adverse effects, school overcrowding, housing shortages, transportation snarls, etc. Indeed, as a second mute on impacts, it may well be that many of the same workers employed in Vermont and at Northfield Mountain may move on to the Corps and M.D.C. projects as the former pair near completion. Of course, timing is a significant factor, but it is reasonable to assume that at least some transfer will be observed when construction commences.

In a post-audit of the labor force assembled for the construction of the hydroelectric facilities at Northfield, fully 84 percent were hired locally. The great majority already lived within commuting distance and spent their pay checks locally. Thus salaries were introduced to the economics of central Massachusetts and southern New Hampshire and Vermont. The majority of the labor force, however, did not reside within the towns of Northfield or Erving. For these communities, then, purchase of meals and incidentals were the major sources of increased spending.

Apart from relatively small economic impacts, social impacts related to suppliers' perceptions of equity are particularly significant. Though, objectively speaking, little real proof of harm can be demonstrated by even the most adamant opponents of implementation, supplier towns feel a kind of moral outrage at being "forced to give up our water".

With respect to the benefits which could accrue to the supplier area, the following three are common to all projects:

1. An improved economy in eastern Massachusetts which would have a positive effect on the whole State.

2. Insurance of a healthier Quabbin Reservoir for present uses.

3. A better aesthetic environment at Quabbin Reservoir because of increased pool levels.

In addition, alternatives No. 1, 2 and 3 would provide:

1. Assurance of a future source of supply, if needed, based on historical precedence of the Metropolitan District Commission in their other (e.g. Wachusett and Sudbury Reservoirs) source areas.

Together with all of the previously noted benefits, Alternatives No. 1 and 2 would also insure the following:

1. A cleaner river than otherwise possible under the present implementation schedule.

2. Larger, more lasting effects on the regional economy occasioned by the waste treatment plant construction and operation. The added requirement for treatment plant operators would probably be drawn from the local labor market.

4. Adverse Environmental Effects Which Cannot Be Avoided Should The Plan Be Implemented

The major impact on the hydrology of the donor systems will be to reduce the peak flows of the rivers during high runoff periods in the spring and sometimes in the autumn. A corollary effect of reducing peak flows, is to reduce the amount of flooded area in the river flood plain downstream. According to the U.S. Geological Survey, recharge of ground water aquifers will not be affected during high runoff periods when diversion would take place since flood conditions are already controlled by Birch Hill Dam and Tully Dam.

During each spring diversion period, about 1-2% of the Connecticut River flow volume will end up in Quabbin Reservoir through the Northfield diversion. An additional 1% would come to Quabbin through the Tully diversions if they were completed. For the spring of 1971, the theoretical figures would have been 1.5% had the Northfield diversion been implemented, plus an additional 0.9% by way of the Tully system. These amounts represent 1% of the total annual flow of the Connecticut River at Montague City. No appreciable impact on the hydrology of the Connecticut River and its watershed downstream from the Northfield diversion site is expected. Berger (1971) has estimated that the Northfield diversion to Quabbin would create a stage reduction of 0.2 foot (2 3/8") at Montague City.

There will be a greater effect on the Millers River system since a larger percentage of water would be diverted during diversion periods, but again no appreciable impact on the hydrology of the Millers River watershed is expected.

5. Alternatives to the Proposed Action

During the planning stage of this report a wide range of alternatives to the proposed diversions were investigated. Included in these alternatives were other possible diversions, use of new technology as a means of augmenting existing supplies, non-structural approaches such as reduction of demand and the evaluation of the no-action alternative. A description of these alternatives and their potential, as solutions to the existing problem, are given in the following paragraphs.

No Action

Within the intent of the National Environmental Policy Act of 1969, we must consider the alternative of no diversion. Mention has already been made of the probable deterioration in water quality in Quabbin Reservoir during Phase I. Extending the time reference beyond 1976, we predict a further deterioration in the condition of Quabbin Reservoir if the projections as shown in Figure 1 are operative. Central to these projections are average inflow conditions and the realization of the projected increases in water supply demand.

An analysis of the dilemma can be approached in terms of classical limnological concepts. Under full pool conditions, Quabbin Reservoir would resemble a temperate lake of the second order (Welch, 1952). Moreover, the condition would be quite characteristic of an oligotrophic lake. In such a lake nutrients are low, electrolytes are low, dissolved oxygen levels are high, algal blooms are rare, and cold-water fishes (salmon, trout) are found in abundance. As the reservoir loses volume, it will approach the conditions of a temperate lake of the third order, the chief characteristic of which is a loss of thermocline and the development of essentially isothermous conditions. Such a lake will move faster toward a eutrophic condition than will a second order lake. Eutrophic lakes are relatively shallow, nutrients are abundant, dissolved oxygen may be absent in deeper layers, blooms are common, and the fish populations are predominantly warm-water fishes (Welch, 1952).

However, the situation at Quabbin Reservoir is complex in that some sections are very deep (over 100 feet), whereas some areas of the northern section are very shallow. Moreover, the reservoir is a dynamic and not a static pool, with substantial, annual inflow-outflow volumes. Therefore, it is very difficult to state at what elevation (or volume) the reservoir will reach a "critical point". Water quality conditions, algal growth patterns, and fishes in the northern sections suggest that progression toward eutrophication is already taking place there. Water quality in the main body is still of a high quality. As the projected volumes decrease over the years, the relative masses of high versus low quality water will shift toward an overall loss in water quality. Losses in volume will decrease the treatment capacity and possibly the retention times of new inflow waters. Losses in hypolimnion volume will certainly diminish the standing crop of salmonid fishes. Finally, at some point in time before total water depletion (1985), Quabbin Reservoir will not be acceptable as a public water supply. Our conclusion, therefore is to regard the no-diversion alternative as unrealistic unless other alternatives, outside the scope of the present project, offer better solutions to the projected Boston metropolitan water supply problem.

Related to the no-diversion alternative is the concept of delays in diverting the proposed riverine sources. Again, we cannot set a critical time limit, after which diversion of riverine waters might pose a higher risk to the maintenance of a good water supply. Several seasons with good inflow into Quabbin Reservoir, such as with the current situation in the spring of 1972, would displace the curve "existing system" of Figure 1 to the right. Another drought period would shift it to the left. Assuming again, as we did earlier, that the supply and demand remains as projected, about half of the current volume of Quabbin Reservoir will remain by the end of this decade. As a first approximation, we are guessing that the relative decrease in water quality, the marked decrease in diluting volume, and the reductions in treatment capacity will increase the risks of diversion if diversion is delayed by four years to 1980. If, on the other hand, the water quality of Quabbin Reservoir decreases faster than we believe during this period of delayed diversion and if the Connecticut River waters improve faster than projected through abatement procedures, we could indeed be faced with a reversed situation, in which the riverine waters are of a higher quality than those of the then-existing reservoir. Irrespective of the exact year, at some point in time, riverine waters will actually be of a higher quality than the reservoir. Under these conditions, it is impossible to predict the final water quality after diversion and retention of Connecticut River water in the then-existing reservoir. We can predict, however, that the maintenance of a good water supply will be greatly impaired following significant delays in the proposed diversions.

In the evaluation of this alternative, it was assumed that any failure to implement additional supplies for the study area would cause socio-economic impacts on serviced communities. To verify this assumption, a quantification of these impacts was necessary.

Estimates of impacts caused by no-action policy can be expressed in two different ways. First concrete losses without the diversion total \$84 million to 1990 and \$738 million to 2020 if average runoff conditions prevailed. Under drought conditions, concrete losses without diversion total \$146 million to 1990 and \$835 million to 2020.

Categories included in these totals encompass industrial, city emergency, city, revenue, commerce, sprinkling, business investment and domestic investment losses. However, economic losses in these categories say nothing of the ways in which the losses might be allocated. For example, of the approximately \$4 million not collected in city revenue in 1990 by all receivers under a no-action policy, there is no way of knowing whether it would be municipal expenditures on recreation or schools that might suffer. In Section 3, this loss in revenue was expressed as 600 classrooms. Similarly, housing units not built are but an alternative manifestation of losses in the private sector.

Social impacts in communities serviced by the supply system under a no-action alternative would be principally "shadow costs" of the concrete losses. As municipal efforts turn to finding other sources of supply, building bans to hold the line on new demands are a likely eventuality.

Second-order effects of expenditures on water searching manifest themselves as slowed school building programs, poorer municipal services (such as fire protection) and a general malaise in the region's development plans. Moreover, it appears that citizens are likely to become discouraged and frustrated as they see their lawns dry up during watering bans. In many ways these feelings are reflected in attitudes about the desirability of their community as a place to live and work. The net result could be stagnated growth, hostility toward other communities able to lure industries unable to locate in the water short municipalities.

Based on the evaluation of the socio-economic and environmental impacts, the no-action alternative has many disadvantages. Use of this alternative, therefore, does not offer a realistic solution to the short range needs of the study area.

Weather Modification

The primary source of the water used for public and private water supply in Massachusetts, as in most humid areas, is precipitation falling directly on the areas concerned. It follows then that if precipitation can be increased in a regulated manner, the water supply can also be increased. To this end several major agencies such as the United States Weather Bureau, the United States Bureau of Reclamation, the American Meteorological Society, and the National Science Foundation are investigating ways of productively modifying natural precipitation patterns. The primary focus of research is in the area of cloud seeding. Other fields of interest are long-term seasonal precipitation forecasting and fog drip augmentation. Since little work has been done on the latter two, and what little has been accomplished is not applicable to the Massachusetts area, only the process of cloud seeding will be reviewed in this section.

A. Cloud Seeding

Simply stated, rain falls from clouds when water vapor in the clouds condenses around nuclei and forms rain drops large enough to overcome frictional resistance to falling. In technical terms, this process is the conversion of the water vapor from a state of colloidal stability to one of colloidal instability. The concept of artificially induced precipitation by cloud seeding refers to the introduction of particles of foreign substances, such as dry ice and silver iodide into clouds to serve as condensation nuclei. Theoretically, this action will result in condensation of the water vapor and consequent precipitation. In short, it is scientific rain making.

The testing of the engineering and economic feasibility of this theoretical process has been concentrated in experimental projects in the Rocky Mountain and Upper Great Plains regions. A cost benefit study was performed for the Connecticut River Basin, but this study was in design only with no actual experimental work involved. Most information regarding the potential of cloud seeding in the eastern United States is derived from commercial cloud seeding operations.

Some of the findings resulting from these studies and experiments are summarized below:

1) The state of the art is such that most researchers look upon the potential of increased precipitation through cloud seeding with an air of cautious optimism. Study to date, however, has provided little more than a beginning to the solution of many of the problems involved in weather modification.

2) Cloud seeding is impractical during severe drought conditions when water shortages are most critical. The first requisite for cloud seeding is the presence of clouds, and droughts are notable for their lack of clouds. Present technology is not even remotely capable of producing clouds by weather pattern modification. During a temporary interruption of drought conditions, clouds may form over an area. Even under these conditions, however, cloud seeding would not appreciably alleviate water supply problems since any precipitation would in all likelihood be taken up immediately by plants. It is apparent then that water shortages in periods of drought cannot be solved by cloud seeding. Any substantial seeding induced precipitation would have to be produced during non-drought conditions with abundant moisture in the atmosphere.

3) There are many problems that must be solved before substantial technological breakthroughs result. One of the most critical is the inability of researchers to satisfactorily define optimum cloud conditions and seeding techniques and to predict seeding results accurately. In other words there is an inadequate understanding of the basic cloud processes which determine: a) the "seedability" of a cloud or cloud system, and b) the proper seeding treatment to stimulate rainfall production efficiently in a potentially seedable cloud.

Another problem is the possibility of undesirable effects of seeding. Indiscriminate seeding might increase soil erosion and sedimentation in streams through intensification of the normal rainfall rate of natural storms. There is the possibility also that artificial seeding of clouds might in fact reduce the natural rain producing capacity of the clouds.

4) Estimates of the feasibility of cloud seeding in the eastern part of the country, including New England, are vague and poorly defined. Most recent cloud seeding research has been conducted in the western states. Atmospheric scientists have cautioned that results of seeding experiments in one area of the country must be viewed with caution when applied to other areas characterized by different topography and climate. It is apparent that much research needs to be done in the eastern part of the country. There is data available for parts of this area from commercial cloud seeding operations. However, these operations were not performed under proper scientific and statistical control procedures and any data gathered in such a manner must be used and interpreted with care.

B. Conclusion

Research has continued to improve the state of the art of weather modification by cloud seeding and other means. At best, however, weather modification is still an inexact science. Studies are unable to predict optimum cloud conditions and seeding results with any degree of accuracy. It is the conclusion of this section, therefore, that at this time weather modification operations to augment water supplies in Massachusetts does not appear to be a viable solution to the immediate water supply problem.

Desalinization

Desalinization, the process in which brackish and salt water is converted to fresh, is currently being used in some parts of the world as a viable, economically feasible source of fresh water. This process thus was considered for its potential as a future alternative solution to the water supply needs of eastern Massachusetts.

The conversion of saline to fresh water is accomplished through four major processes: distillation-evaporation, membrane separation, crystallization, and chemical differentiation. A descriptive summary of each process is given below.

A. Distillation-Evaporation

In this process, water containing salt or other impurities is heated and vaporized. The water vapor, free from the salt and other solids which remain behind as the water boils, is then condensed and collected. The system is basically a simple one requiring only a source of heat energy to boil the water, a method of cooling the water vapor (condensation) and various kinds of plumbing and receptacles for the transfer and storage of the water.

Since distillation, by its nature, results in the complete separation of the water vapor from the dissolved salts of the influent, the process produces fresh water of exceptional purity. Because this method removes the water from the salt, rather than vice versa, the quality of the influent is not critical and the system works equally well on water with a high salt content as an only slightly brackish water. For these reasons, among others, distillation is the oldest and best-known process of desalinization.

B. Membrane Separation

Desalinization by the membrane process is based upon the ability of thin membranes to pass molecule of pure water and retain the ions of salts and other dissolved solids. There are three basic variations to this concept: a) electrodialysis, b) transport depletion, and c) reverse osmosis. The first two variations depend on the electrical properties of the ions involved, while the third depends on a pressure differential existing across the membrane. Of these three variations, the electrodialysis process is the most well established, with many commercial installations throughout the world.

In contrast to distillation, the membrane process separates the salt from the water rather than the water from the salt. Each stage of the electrodialysis process removes slightly less than 50% of the dissolved solids in the water being treated. The more saline water, the more stages are needed and hence more energy is consumed. For this reason, electrodialysis and other variations of the membrane process are more economical when used with brackish water with a salinity of between 5,000 - 10,000 mg/1, as opposed to more saline water. The water can then be refined in stages to the desired degree of purity.

C. Crystallization

This process relies primarily upon the fact that as water freezes, the ice crystals reject ions of salt. Saline water is frozen and the crystals of pure ice are then skimmed or removed for later use from the still liquid brine. A second method of separation by crystallization employs the hydrate process which is the formation of a crystalline substance by the combination of water with low molecular weight, hydrocarbons or their derivatives. Like ice crystals, these hydrates reject salt ions. It takes less energy to freeze water than it does to boil it, thus this method has an advantage over distillation in that it consumes less energy. The crystallization process has not been widely used, however, and further research into its effectiveness is continuing.

D. Chemical

In this process either the water or the dissolved salts are made to undergo a chemical reaction which forms a substance which can be easily separated from the untreated water. Ion exchange, a method by which the saline water is passed through treated resin and the salt ions selectively removed, is the most widely used method of chemical desalinization.

The efficiency of ion exchange decreases with time as the "holes" in the resin become filled with salt ions. Once the resin is saturated, the operation must be closed down and the resin regenerated. For these reasons, the process has had only local exposure and small volume use.

E. Present Application

Sea water can be considered, for all intents and purposes, an unlimited source of fresh water once the technology of desalinization is refined to a point where it is economically feasible. To this purpose, the federal government, through the Office of Saline Water, has promoted extensive study and research into the problems of desalinization. Several model and testing plants and facilities have been constructed to aid in these studies. The research to date concludes that of the four main processes discussed above, distillation and membrane separation are best suited to large capacity plants. Economical considerations dictate that distillation is best for sea water and electrodialysis for brackish water.

Many desalting plants are currently in operation in areas where there is a pronounced lack of fresh water supply. Certain areas in Africa, the Middle East, the Island of Malta and the Carribean Islands are representative examples. A distillation plant in San Diego produced 1.4 mgd and an electrodialysis plant in Buckeye, Arizona has a capacity of 0.65 mgd.

A distillation plant is presently proposed for San Louis Obispo and Santa Barbara Counties, California, which will have a capacity of 40 mgd. Construction on this plant which will be the largest in the world is scheduled to begin in 1973.

F. <u>Costs of Desalinization</u>

The cost of fresh water produced by desalinization depends upon the capacity of the plant, the type of process used and whether nuclear or fossil fuel is used. In general, the larger the plant capacity, the less the cost per unit of water. As has been mentioned previously, distillation is more economical for the desalting of sea water, while electrodialysis is better for brackish water. The water costs from nuclear fueled plants are approximately 10% less than from fossil fuel used in large capacity (more than 100 mgd) plants.

The current cost of desalting is about one dollar per thousand gallons. This estimate is based upon an output capacity of 1 mgd, an amount representative of many plants currently in operation. Designs for the larger plants, such as for San Louis Obispo and Santa Barbara Counties, California, indicate costs in the vicinity of 73 cents per thousand gallons.

G. <u>Conclusion</u>

Desalinization by numerous processes is already feasible in parts of the world when the natural supply is either scarce or of poor quality. In these areas, the relatively high costs of water produced by desalinization are justified. Research has indicated that when larger capacity plants are designed and in production, the costs could ultimately be reduced to approximately 40¢ per thousand gallons, although the proposed California plant would produce water at 73¢ per thousand gallons. Even at this reduced cost, however, desalinization is not competitive with present costs of developing natural surface and sub-surface water supplies. For example, the cost of water from the Northfield Mountain diversion is about 14¢ per thousand gallons.

Aside from the economic costs involved with desalinization, the Office of Saline Water is also investigating the potential hazards to the environment which might occur from disposal of waste brine. This brine from distillation plants is of high temperature, higher chloride content and may contain concentrations of copper, all of which could prove injurious to the environment. As a result, this report concludes that desalinization not be considered at this time as a viable alternative source of water in eastern Massachusetts for the short-range water supply problems. When and if the technology and efficiency of this process is refined so that it is economically and environmentally competitive with other methods of supplying water, its feasibility can be re-evaluated.

Importation

During the crisis years of the sixties' drought, many newspaper and periodical articles pondered the possibility of diverting water from extra-regional sources as a solution. One of the major basins often mentioned as a water supply source for the Northeast was the Saint Lawrence. As an alternative to developing local resources to meet future water needs, an investigation was made regarding the feasibility of diverting Saint Lawrence flow to meet future needs.

The Saint Lawrence River Basin is an impressive basin both in its size and the annual runoff from its watershed. The drainage area is about 295,000 square miles at Ogdensburg, New York, which includes over 95,000 square miles of water surface area, most of which is in the five Great Lakes. Storage capacity within the lakes regulates the flow in the river to a large degree. The long term average discharge at Ogdensburg is about 240,000 cubic feet per second (155,000 mgd). From a review of these statistics, it is apparent that the basin, if developed, could meet the forecast supply demands for all of southeast New England.

Engineering studies were conducted to assess various methods and quantities of development from the basin. Cost estimates were prepared for projects which would service all of the Northeast through the year 2020. Construction costs for such facilities were estimated to be as high as 8.5 billion dollars excluding any necessary water treatment costs. Water delivered from such an undertaking would cost substantially more than similar volumes made available from local resource potential.

In addition to the high cost of water, this alternative also has several other major disadvantages. First, the nature of the project would not allow stage development. Thus, large expenditures of funds would be required for distant long range needs. Second, since the basin is international, negotiations with Canada would have to be held and a treaty consummated prior to diversion. Assuming that Canada would be favorable to such negotiations, at best, any treaty would be in the distant future.

Based on the results of investigations conducted as part of this report, the importing of water to meet short-range water supply needs does not present a viable alternative for the southeastern New England Region.

Waste Water Reuse As A Municipal Supply

Waste water reuse, especially in industrial process application has been economically successful in many sections of the country. The Bethlehem Steel Company in Baltimore, Maryland currently uses about 120 mgd of treated municipal waste from Baltimore and uses this effluent in its quenching and cooling processes. The Dow Chemical Company uses treated sewage from the City of Midland, Michigan for use in its cooling water and fire protection system. In Amarillo, Texas, effluent from the municipal sewage treatment is used as cooling water and boiler make-up water for industries located in that city.

Other uses to which treated waste water has been applied include irrigation of both crop land and lawns, as a fresh water barrier against salt water intrusion, and in some cases as a source of supply for formation of recreation lakes and ponds.

Direct reuse of waste water effluent as a public water supply, however, has not been utilized to a large degree. Advanced waste treatment research and development programs at the Federal level are continuing and pilot plant studies such as the noted Lake Tahoe project are apparently meeting with some success.

The current Drinking Water Standards do not apply to direct reuse of reclaimed water for drinking. In a series of recent articles, the Division of Water Supply Programs, Environmental Protection Agency (formerly Public Health Service) has described a number of potential health programs which could occur with the use of renovated waste water. Recent public repercussions from birth defects caused by thalidomine and from the side effects of other new drugs, underscore the responsibility that health officials have in introducing or promoting the use of reclaimed waste water as a domestic source.

Health officials feel many questions remain unanswered which must be fully investigated if renovated waste water is to be considered for drinking water purposes. Research considered vital was described in an article[1] prepared by the Director and Deputy Director, Division of Water Supply Programs. In their article it was stated that before development of intimate personal-contact uses of renovated waste waters, one needs to

A. Initiate studies on viruses for

1) Development of improved viral detection and enumeration methodology.

2) Exploration and definition of the basic properties of enteric viruses.

3) Provision of knowledge on transmission of viruses through the aquatic environment.

4) Definition of the impact of viral disease on man through associated epidemiological studies.

5) Development of technology for the positive removal and inactivation of viruses.

1 Lang, W.N. and Bell, F.A., "Health Factors and Reused Waters," Journal American Water Works Association, April 1972.

B. Investigate the potential problems from bacteria and other micro-organisms in reclamation systems.

C. Identify and define the potential health effects of organic and other chemicals not removed by reclamation plants and subject to build-up, and develop techniques to identify and measure readily the concentrations of such chemicals.

D. Dispel the cloud that hangs over the whole subject of reliability for wastewater-treatment-plant operation. Reclamation plants for direct reuse must have fail-safe processes, back-up facilities, alternate means for disposal, continuous monitoring, and bioassay, and they must be operated in an atmosphere that demands reliability. State programs responsible for the operation of wastewater-treatment plants will require upgrading. Pilot and field-scale testing will be required for the validation of processes and practices prior to their widespread use.

E. Use common sense. Renovated wastewater should not be used for the ultimate personal use -- as a drinking-water supply -- until there is no other practical choice; and then, hopefully, the minimum research will have been completed and the use will be carefully operated and controlled. Meanwhile, in water-short areas, the renovation and reuse of wastewaters for industrial, limited irrigation, and other low human-contact purposes should be investigated and advanced.

The future of direct wastewater reuse particularly in industrial applications seems promising. Future water demand forecasts for industrial usage in fact, anticipates greater recycling of water in the industrial sector.

Use of renovated waste water as a regular domestic supply, however, requires full results of proposed research. Until such research is completed, waste water reuse as a municipal water supply is not a viable alternative to meet short-range supply needs.

Ground Water Resources

A study of the ground water resources of Massachusetts was prepared for the Corps of Engineers by the United States Geological Survey. The study was based upon analysis and interpretation of available data and did not include any new exploratory work. The objectives of the study included an estimate of the area extent and sustained yield of principal aquifer reservoirs which might be used for supplementing municipal and industrial water supplies. The cost of producing the water was also estimated.

A. Occurrence of Ground Water

A water bearing strata of rock material is called an aquifer. The principal aquifers underlying Massachusetts are of three types: 1) Stratified drift, layers of sand and gravel commonly interbedded with some silt and clay; 2) till, a non-stratified, poorly sorted mixture of clay, sand, gravel and boulders; 3) crystalline metamorphic and igneous bedrock. Till and bedrock aquifers yield small amounts of water, suitable only for domestic supplies. Only those aquifers occurring in stratified drift have the potential capacity to sustain large withdrawls of water.

Geologic reports and well logs were studied to determine the distribution and thickness of stratified drift deposits in Massachusetts. Deposits were found about everywhere in the state but were most extensive in the valleys and outwash plains of the east and southeast area.

B. Hydrologic Parameters

In order to evaluate the aquifers as potential sources of water supply, their water transmitting and storage characteristics were studied. Permeability values, in gpd/sq. ft.,were assigned to various lithologies such as gravel, sand and gravel and coarse-medium-fine sand on the basis of the relationship between grain size and permeability. The transmissibility, in gpd/ft., of a lithologic unit was then determined by multiplying the thickness of the unit by its permeability value. Coefficients of transmissibility and storage were also calculated from controlled pumping and drawdown tests at wells sunk in the aquifers.

The saturated thickness of the aquifers were mapped where data was available. The thickness was determined by subtracting the elevation of the base of the aquifer from the water table elevation. The saturated thickness of stratified drift, although not necessarily indicative of the presence of permeable zones, has been found by investigators to be a useable favorability guide for a general analysis of the ground water withdrawal potential. One further indicator of the water content of a ground water reservoir is the percentage of surface stream flow which is contributed by ground water. This portion of stream flow is termed base flow or ground water runoff. Analysis of past records indicate that average annual base flow of a given stream is approximately equal to Q-60 (stream flow equalled or exceeded 60% of the time) in a year of normal climate and equal to Q-70 in a dry year. The Q-70 flow is considered an index to the amount perennially available for consumptive use without depletion of storage.

The hydrologic criteria described above were applied to the principal aquifer reservoirs of Massachusetts. In this manner the capability of these reservoirs to serve as alternate sources of water supply could be evaluated. The rates of withdrawal from the aquifers were estimated by assuming the following conditions:

1) No recharge occurs for 200 days in dry years and all the water produced during this period is from ground water storage -- it is assumed that reservoirs capable of sustaining withdrawals under these conditions could continue producing forever;

2) The configurations of the reservoirs were idealized to form elongated rectangles;

3) A system of dewatering wells, 24" in diameter and spaced 2,000 feet apart for 2 mgd yields and 1,000 feet apart for 1 mgd yield, was hypothesized to aid in planning and cost estimates;

4) These wells were assumed to have no drawdown attributed to partial penetration, thinning of the reservoir, nor well losses;

5) Available drawdowns in the wells were limited to two thirds of the saturated thickness for water table conditions and to the top of the producing reservoir for artesian conditions;

6) Current withdrawals of ground water were included as a part of the estimated withdrawals.

The results were then tabulated by area and rate of withdrawal in mgd/sq. mile and total withdrawal in mgd.

C. Conclusions

The survey of ground water resources indicated that the aquifers in Plymouth County and parts of Cape Cod have the capacity to sustain long term, large magnitude withdrawals. The water demand on Cape Cod is increasing at a fast rate; therefore, this area is not considered in this report. The Plymouth County area studied comprises 300 square miles and its estimated safe yield is 300 mgd. This estimated rate exceeds the required quantity established as a goal at this study. Thus, it was concluded that the Plymouth County area could offer a viable alternative source of water supply for eastern Massachusetts.

Cost estimates for the necessary resource development were then prepared. On the basis of these estimates, it was determined that such a ground water resource alternative would be much more costly than Northfield Mountain plus any one of the Millers River basin alternatives. In addition to economic costs, potential socio-economic costs associated with land taking activities for protection of the wells and interference with shallow recreation lakes in the region appear to be excessive also.

On the basis, then, of cost comparisons and potential socio-economic impacts, use of ground water does not appear to offer an attractive alternative to the proposed projects.

Dual Water Supply Systems

An alternative which has been receiving attention of late has been the use of dual water supply systems. In these systems a hierarchy of water supply would be established whereby higher quality supplies could be used to furnish a potable source for drinking, cooking, dishwashing, cleaning, bathing and laundering. All other uses could be furnished by a second supply of lesser quality.

Two general methods have been suggested for such a dual system. The first is the possibility of recycling at the point of usage. Under this scheme, drinking, washing and bathing water would undergo treatment and then be further utilized as toilet flush water and outdoor uses. It is estimated that such a system could reduce domestic water use by as much as 50%.

Various systems for in-house reuse or for outdoor usage have been proposed and some are being marketed on a small scale.

Advantages to this system beyond potable water consumption reduction is the reduction in sewage water volume, sewer pipe and pumping requirements. Capital cost outlay for such a system based on limited cost data would again be much more expensive than water delivered from the proposed projects. Other disadvantages to this alternative lie with its limited application and accompanying operational experience, potential problems of odor and other aesthetic considerations. Health officials in general have not expressed their acceptance or rejection of such systems. However, their general apprehension on introducing less than potable water into the home environment could also reasonably be expected with regard to any system of this nature.

The second method which has been suggested for delivering higher and lower quality water for various uses would require a second distribution system. This second distribution system would carry river water or even sea water to supplement the high quality primary supply source.

Two methods of providing the second (lower quality) distribution system could be employed. The first would involve installation of the entire system immediately. The second, and more practical, method would be on an incremental approach wherein secondary systems are installed in new or replacement buildings above a certain size. The second approach is evaluated in this statement. With this approach, water consumption is only reduced at a given time by the building construction that utilizes secondary systems.

To estimate costs for such a system, a report on the New York City area prepared as part of the NEWS Study was utilized. Based on the results of that investigation, preliminary capital cost estimates for such a dual system would be about 6.5 million dollars per mgd saved. The Northfield Mountain diversion project alone is estimated to cost only about $550,000 per mgd. Therefore, it is quite apparent that use of a dual supply distribution system as an alternative would be an extremely expensive alternative.

In summary, then, use of dual water supply systems does not offer an alternative to the proposed projects in this statement. Of the two methods, the system which would recycle water at the point of usage holds the more promise for future application.

Other Diversion Sites

In addition to the Northfield Mountain Diversion and Millers River Basin Diversion proposals described in this environmental statement, a number of other diversion possibilities were also evaluated. These other possible sources included diversions from: the mainstem Connecticut River at other than the Northfield Mountain location; other major tributaries of the Connecticut River; the mainstem of the Merrimack River and the Sudbury River, a tributary of the Merrimack, formerly used by the MDC.

A. Other Connecticut River Basin Alternatives

Alternative methods of diversion from the Connecticut River Basin such as the Deerfield River or another location on the Connecticut River could provide an equivalent yield to that of Northfield Mountain. Development, however, would be more expensive than either the Northfield Mountain or Millers River proposals. Aside from economic costs, this alternative does not appear to present any clear cut advantage from either an environmental or socio-economic standpoint. It appears then that development of alternative sources would offer an opportunity for providing the necessary short range water supply need. Their development, however, would be more expensive and would not offer any advantage over the project presently under consideration.

B. Merrimack River Basin Alternatives

1) Merrimack River Mainstem

As an alternative to further diversions from the Connecticut River Basin, the potential of developing the Merrimack River mainstem to meet short term needs was also investigated. Based on studies to date, use of the Merrimack River to meet long range needs, that is, beyond 1990, holds promise. Use of the river to meet short range needs, however, does not appear to offer an attractive alternative from either an economic or public health standpoint.

At present, the physical, chemical and bacteriological quality of the river is poor. For years the river has been subject to major discharges of municipal and industrial wastes. Because of these discharges, the Merrimack is often characterized as one of the ten most polluted rivers in the United States.

Even with the existing pollution load, the mainstem river is now used as a water supply for the Cities of Lowell and Lawrence. Water treatment facilities for both municipalities are conventional; however, taste and odor problems are experienced periodically at both locations.

Pollution abatement programs to implement secondary waste treatment facilities on point sources of pollution are under way by state and Federal agencies. Costs of these plants are estimated to be 235 million dollars. Upon completion of the abatement programs scheduled for 1976, the river will be improved as a water supply source.

A recent report by the Corps of Engineers[1] in cooperation with the Environmental Protection Agency investigated the feasibility of various alternatives for upgrading treatment processes beyond the planned implementation schedule. Cost estimates of the various alternatives ranged from 668 to 1108 million dollars. All of these plans would further enhance the quality of the river for use as a water supply source.

To develop the Merrimack River as a water supply source for the short range needs (1990) would require an intake structure, pumping facilities and a transmission main about 21 miles long. Cost estimates of this alternative, depending on degree of waste and water treatment, and size of pumping and transmission facilities, would be in excess of those necessary for the Northfield Mountain Project.

1 "The Merrimack: Designs for a Clean River," North Atlantic Division, Corps of Engineers, September, 1971.

2) Sudbury River

In 1872, the Sudbury River Act was passed which authorized the diversion of a portion of the Sudbury River waters to the Boston Water System. Subsequent to this Act, a series of reservoirs were constructed by the Boston Water System and later by the Metropolitan Water District to develop the watershed. Construction on the last reservoir in the basin was completed in 1898 and a total of 75.2 square miles of drainage area was controlled.

In 1947, in response to the availability of supply from Quabbin Reservoir and the higher quality supply from this source, the Massachusetts Legislature transferred control of a number of the reservoirs to the Department of Conservation. The reservoirs transferred represented about 50 square miles of drainage area and were subsequently developed for recreational usage and their water supply use discontinued.

With its available supplies unable to meet its short range needs, the Metropolitan District Commission has reevaluated the potential which the full Sudbury system may have. Based on initial studies, it appears an additional 40 million gallons per day may be made available through flood skimming techniques.

The Sudbury Basin waters, however, have a number of water quality problems. Thus, to provide the potential yield, water treatment facilities would be necessary. Preliminary cost figures for needed facilities are estimated to be about 43 million dollars. In addition, transmission and pumping facilities may be necessary.

In order to fully estimate the potential and costs for redeveloping the Sudbury system, the MDC is requesting funds from the Massachusetts legislature.

In summary, the "redevelopment" of the Sudbury River basin could add an attractive increment to the available water supplies being studied. Based on preliminary cost estimates this increment is expected to cost considerably more than the Northfield Mountain diversion. Yet to be determined as part of the MDC further study are the environmental and socio-economic advantages and shortcomings. In addition, even if implemented, another supply would be necessary to meet short range needs.

C. Conclusion

Alternative development of the Connecticut or Merrimack Rivers was evaluated as methods of meeting short range water supply needs forecast. Although either river basin offers opportunities, their development would be more expensive than the proposed project. In addition to economic considerations, use of the heavily polluted Merrimack River does not appear to offer an attractive alternative from a water quality standpoint for short range needs.

The Sudbury system plan needs further study for a full assessment of its potential. If the Sudbury "redevelopment" plan were to be found attractive and constructed, however, it would be fully compatible with any of the other proposed projects.

Water Demand Control

The NEWS Study, cognizant of the narrow margin separating available yield and consumer demand, conducted studies on methods available to alleviate this critical water supply situation. Two general approaches to the problem were investigated: The first considered various methods of increasing the supply available to the system. The second approach described in this section was investigation of methods whereby demand could be curtailed.

A. Components of Demand

1) General

Water demand can be classified into four main categories. These are Domestic, Public, Commercial and Industrial. Nationally, of water withdrawn from public systems, 46 percent is delivered to domestic consumers; 13 percent to public uses; 18 percent to commercial; and 23 percent to industrial applications. A description of uses to which water is applied in the various categories is given in the following paragraphs.

2) Domestic

Domestic use, for purposes of this study, includes that water used by the consumer both within his home and that used by him for allied residential uses such as lawn sprinkling and car washing. In house, uses of water include drinking, bathing, cooking, washing, and carrying away of wastes.

Total domestic water use in the United States amounts to approximately 73 gpcd. Few studies have been conducted regarding the composition of this demand; however, the U.S.G.S. reports domestic water in Akron, Ohio was used in the following proportions:

TABLE

Domestic Water Use		
Carrying away of wastes		41%
Bathing		37%
Cooking and Washing		9%
Drinking		5%
Clothes Washing		4%
Lawn Sprinkling		3%
Car Washing		1%
	Total	100%

3) Public

Public or municipal use on a national basis accounts for about 28 gpcd of the average 143 gpcd supplies by public water utilities. Water used in this category is delivered to municipal facilities such as administration buildings, schools, hospitals, golf courses and other facilities used by the community at large. The water delivered in this category, of course, reacts to number and type of services provided. In Boston, for example, with a large number of hospitals and other institutions, it is reported 38 percent of total water use falls within this category. In Wellesley, a suburb of Boston, only 9 percent is recorded as public.

4) Commercial

A significant portion of all water delivered from public supply systems is used by commercial establishments. Nationally, it is estimated about 28 gpcd are used for this purpose. Within this category is included department stores, restaurants, hotels, laundries and other service elements which serve the general public. No breakdown of water delivered to the commercial sector was available for the Boston Metropolitan area, but it is estimated 850,000 commuters travel daily to the City of Boston. Water supplied to these commuters for their needs while "temporary residents" cannot help but be a significant share of the water supplied to the City.

5) Industrial

Many industrial establishments obtain their water supply from public utilities. Of the average 157 gpcd recorded in the United States, 36 gpcd were used in industrial plants. The water withdrawn by these industries is used for three principal reasons: cooling water; boiler water or water used for the generation of steam and process water, which is water that comes in contact with the product being manufactured.

Available records on industrial use which record individual community usage are limited. On a state-wide basis, about 100 mgd or 13 percent of the publicly supplied water was drawn for industrial use in 1968. Within the MDC service area, a recent telephone survey conducted by the NEWS Study indicated about 8 percent of water withdrawn was used for industrial. On this basis, then, Massachusetts and the MDC service area are not heavy industrial water users if compared to the national percentage of 23 percent.

B. Methods of Controlling Demand

There are basically three methods which have been suggested as effective in controlling demands on water supplies. These are:

a) Changing from flat-rate to metered supply

b) Increasing the price of metered supply

c) Imposing of restrictions on water use

Each of these methods outlined above, i.e., metering, pricing, restrictions are described in the following sections as they might apply to the demand forecasts discussed in this environmental statement.

1) Metering

The installation of meters which measure the amount of water used by a consumer has been shown to be effective in varying degrees in reducing demand for water supply. With metering, the customer is now charged for the quantity of water used, instead of being charged a flat rate for a period of time regardless of quantity used. Most of the studies conducted regarding the effects of metering indicate domestic in-house use is relatively in-elastic, but lawn sprinkling use and some industrial applications apparently are affected.

Use of metering then appears to present a good opportunity for conservation of a resource. In the Boston area, however, application of this technique to reduce demand is quite limited. Most municipalities in eastern Massachusetts already meter extensively. For example, the MDC system is presently 96 percent metered. Complete metering, therefore, would affect only 4 percent of service connections in this system and not, therefore, affect to any significance water supply demands forecast in the NEWS Study.

2) Pricing Effects on a Metered Supply

a) General

A number of articles have appeared in recent years in water supply and water resource professional journals regarding the impact of price increases on water demand. All of these articles attempt to quantify the constraining influence which pricing may have upon demands. Generally, the authors, however, are forced to base conclusions on a generally incomplete and sporadic empirical data base. In the following paragraphs, a brief description of these empirical studies is given. Following the study descriptions, an application of the empirical data findings to the eastern Massachusetts forecast demand is made for both the domestic and industrial water components. Finally, an attempt is made to correlate the results of the empirically derived data to the local water supply system experiences.

b) Prior Studies

In 1957, H.F. Seidel and E.R. Baumann[1] prepared a statistical analysis of various water works data. In their analysis, the authors derived an elasticity coefficient of 1.0 for certain price levels and a lower, inelastic coefficient for lower price levels. The authors, however, noted that they remained skeptical that a rate adjustment has the prompt, proportional effect on water use which the elasticity coefficients suggest. They stated their review revealed that most rate adjustments are moderate enough and water use habits sufficiently stable to consign the rate factor to a "distinctly minor role as an influence on fluctuations in water use."

1 Seidel, Harris F. and Baumann, E. Robert, "A Statistical Analysis of Water Works Data for 1955," Journal of the American Water Works Assoc., XLIX, No. 12 (December, 1957).

Linaweaver, Geyer and Wolff,[2] during the years 1961 - 1966, conducted studies to determine patterns of residential water use and factors influencing this use. The results were then used to determine design criteria for water supply systems. These studies were sponsored by the Technical Studies Program af the Federal Housing Administration, and were in cooperation with sixteen water utilities in various climatic regions. Both residential and apartment areas were studied. Climate, economic level of consumers, and pricing systems were considered and concluded as having in that order the major influences on water use.

The economic level of the consumer was considered to influence water use for several reasons. A consumer in a higher valued area is likely to have more water using appliances which increase the overall domestic use. A second reason advanced is that a higher-priced house usually has a larger lawn which will increase the sprinkiing demand. Climate is a major factor influencing sprinkling use when there is a lack of precipitation, but it has little effect on in-house use.

The cost of water also influences the demand. Based on their findings, the authors conclude cost does not influence in-house water use to a great extent, but would decrease sprinkling use.

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2 Linaweaver, F.P., Jr., Geyer, John C., and Wolff, Jerome B., A Study of Residential Water Use, Washington: Department of Housing and Urban Development Report TS-12, February, 1967.

Howe and Linaweaver,[1] using the results of the Residential Water Use Study,[2] studied the effect of water pricing in residential areas. Included in the results of this study was the formation of two equations which, according to the study, described the relation of price on use.

The domestic in-house demand was considered best expressed by the following linear equation:

$$g = 206 + 3.47\ v - 1.30\ p$$

where g = gallons per day per dwelling unit
v = market value of dwelling unit in thousands of dollars
p = price per 1000 gallons in cents

By use of this equation, the authors concluded that the effect of price on demand and the price elasticity of domestic use could be determined.

Based on their use of this equation, Howe and Linaweaver next concluded that domestic in-house use represented a demand relatively inelastic with respect to pricing changes.

Effect on summer sprinkling demands by pricing was considered as described by the following equation:

$$g = 3657\ r^{0.309}\ p^{-0.93}$$

where $r = b\ (w - 0.6s)$

and p = price per 1000 gallons in cents
b = irrigable area in acres surrounding dwelling unit
w = average summer potential evapotranspiration in inches calculated by the Thornthwaite method about 10" in the eastern United States
s = summer precipitation in inches

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1 Howe, Charles E. and Linaweaver, F.P. Jr., "The Impact of Price on Residential Water Demand and Its Relation to Systems Design and Price Structure,: Water Resources Research, III, No. 1 (1967).

2 Linaweaver, F.P., Jr., Geyer, John C., and Wolff, Jerome B. A Study of Residential Water Use, Washington: Department of Housing and Urban Development Report TS-12, February 1967.

From use of this equation, it was determined that the sprinkling demand was responsive to price change. The Howe and Linaweaver work indicated, then, that residential water demand is dependent on the price charged. Typical in-house demands exhibited a price elasticity of -0.23[1]; e.g., a 10% increase in price will reduce demand by 2.3%, while the price elasticity for sprinkling demands was 0.93. Sprinkling use is, therefore, more strongly affected by price change than domestic use. The authors felt that pricing could be used as an effective tool to decrease average day demands and increase revenue.

Because of the different industrial water use requirements and variations in plant process flexibility, a single elasticity coefficient for all industrial use is probably unattainable. Research in this field appears quite limited. One small scale study, however, has been undertaken within Massachusetts and the results of this study are described in the following paragraph.

Coefficients of elasticity for water demand response to pricing changes were studied by Stephen J. Turnovsky.[2] This study was primarily directed to the question of the response of individuals to an uncertain supply of water. From data collected from a sample of Massachusetts towns, the coefficient of elasticity derived for household use was around 0.3, and for industrial demand, about 0.5.

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1 based on a house market value of $20,000 and cost of water at 40¢/1000 gallons.

2 Turnovsky, Stephen J., "The Demand for Water: Some Empirical Evidence on Consumers Response to a Commodity Uncertain in Supply" Water Resources Research, V, No. 2 (April, 1969)

c) Application of Prior Study Conclusions to Eastern Massachusetts

As described in the previous paragraphs, both Howe-Linaweaver and Turnovsky have developed equations and price elasticity based on empirical data which suggest the influence which pricing may have on demand. In an attempt to determine the significance of these relationships to current water demand in eastern Massachusetts, a computer program using these relationships was developed for communities serviced by the MDC.

Once the computer program had been developed, a series of hypothetical price increases were imposed on the existing municipal rate structures. The effect of these increases on both domestic or in-house use and lawn sprinkling requirements are shown in the following table:

TABLE

Effect of Hypothetical Water Supply Rate Increases on MDC Demand

Theoretical Decrease in Domestic Demand (mgd)

Price Increase ¢/1000 gals	Domestic Demand	Lawn Sprinkling Demand	Industrial[1] Demand	Total
5	4.3	1.2	1.4	6.9
10	8.6	2.1	2.7	13.4
15	13.0	2.9	4.1	20.0
20	17.3	3.5	5.4	26.2
30	21.6	4.1	8.3	34.0
40	25.9	4.6	10.7	41.2
50	34.5	5.3	13.7	53.5

1 does not include partially serviced communities.

d) Discussion

As illustrated in the Table price adjustments would appear to offer an alternative to development of supplemental water supplies. Theoretically, a price increase of 50¢ per 1,000 gallons could be expected to reduce domestic or in-house demands by about 34 mgd and a corresponding decrease in lawn sprinkling demand by about 5 mgd. Industrial water use demands are indicated to react by decreasing almost 14 mgd. The total theoretical decrease on the system then with such a price increase would be about 53 mgd.

On the basis of the theoretical equations then pricing would appear to be a valuable tool for conservation of the water resource. A number of questions, however, arise concerning the direct application of these forecast decreased demands to the water supply situation at hand.

First, the empirical data used in the derivation of the domestic use equations, although the most extensive to date is far from all inclusive. Data used was derived from 21 areas nationwide, which contained about 5000 dwelling units. None of the test areas were located within southeastern New England, although data available from the Middle Atlantic States was used.

In the analysis of industrial water demand reaction data utilized was quite limited, and other research in this area is almost non-existent. Development of any hard policy conclusions based on such sketchy information is, therefore, uncertain at best.

Second, the derivation of the empirical equations for domestic use was based on a "static" view of cost versus use. That is, the data employed was not an observation of a group of communities actual reaction to pricing changes. Rather the equations were developed by using a number of communities, which for a given point in time, had different water use with their individual rate structures. For example, Community A in 1970 used 100 gpcd at a cost of 20¢ per thousand gallons; Community B in the same year recorded an average use of 50 gpcd at a cost of 40¢ per thousand gallons. Based on the approach used by Howe and Linaweaver, the expected decrease in use from Community A with a price increase to 40¢/1000 gallons would be 50 gpcd. Whether the use of such a "static" scenerio to predict dynamic conditions is valid is unknown.

That the equations may not indeed reflect the dynamic situation which would occur with a price increase is particularly suspect with actual operating experience in the Boston Region. For example, in the Boston Region, the MDC increased wholesale prices for its water from $40 to $80 per million gallons in 1954, and $80 to the current $120 per million gallons in 1962. Neither of these price increases was accompanied by a decrease in per capita demand on the system, in fact, demand increased on the system.

To further evaluate the dynamic impact of pricing in an actual operating experience, s survey was made of a privately owned water company which recently applied a 24¢ per 1000 gallons to its water rates. This rate increase raised the cost of water to the consumer from $1.00 to $1.24 per 1000 gallons. The two communities serviced by the company are principally residential, thus the rate increase based on the empirical equation should be expected to result in a demand decrease. The company reports, however, that instead of experiencing a decrease in per capita usage, it experienced a 5 gpcd increase.

Based on the actual operating experience of these utilities within Metropolitan Boston, it appears any arbitrary adoption of the empirical equation as a forecast tool with respect to water demand carries a large degree of uncertainty.

Third, all of the studies upon which the pricing-demand relationship was developed have been basically economic studies. No attempts have been made to evaluate or quantify cost to the consumers from either environmental quality or social considerations. For example, in the Howe and Linaweaver study, they note the basic data exclude, among other items, "the costs to society of failure to meet demands or of permitting pressure drops to occur." They further conclude that "An optimum design presumably should balance system development costs at the margin against the expected value of losses incurred when the system fails to meet demands. Nothing systematic is known about such losses, in spite of the widespread occurrence of drought and shortage in recent years." Presumably, the authors' reference to "such losses" includes social and environmental costs which would be borne by the consumer.

Both the social and environmental costs of reducing water demand may outweigh the gains derived from institution of such a policy. Whether, in fact, the costs would outweigh the benefits is unfortunately unknown.

In summary, use of increased water supply prices as a method to conserve a resource may have merit. Yet to be determined, however, are data to support the theoretical impact such increases would have upon the demand within New England. Also unknown with this approach are the social and environmental costs which would be borne by the consumer. It appears then that much work remains to be done on this approach such that it can be evaluated as a viable alternative to increased supply.

3) Imposing of Restrictions on Water Use

Historically, water utilities have used water use restrictions as a "safety factor" against depletion of supply during a drought. In general, however, most water utilities attempt to avoid restrictions whenever practical. Public reaction to such restrictions, however, is almost always unfavorable, and many examples of such public disapproval can be found in newspaper clippings during the recent sixties' drought.

Imposition of restrictions on water use could not fail to interrupt the existing and planned life styles of communities serviced by a water supply system. As described in the appendix on socio-economic impacts, restrictions on water use, depending on its degree, would have far reaching social and economic costs. On the basis of costs which would be incurred with a restriction policy, it does not appear to offer a viable alternative.

Re-examination of the Swift and Ware Rivers Downstream Release Schedules

At the time diversions were contemplated from the Connecticut River Basin, via the Swift and Ware Rivers, Massachusetts applied to the Secretary of War for authority to make the proposed diversions. After hearing arguments pro and con from Massachusetts and Connecticut, the Secretary permitted diversion of the flood waters of the Ware in excess of 85 million gallons per day between 15 October and 15 June and prohibited the taking of any water except during that period.

With regard to the Swift River, the Secretary permitted diversion of all waters of the Swift except enough to maintain a flow therein of 20 million gallons per day (mgd) or 31 cubic feet per second (cfs). The

Secretary did require that during the period from 1 June to 30 November there shall be released from the impounding dam 71 mgd (110 cfs) whenever the flow of the Connecticut River at Sunderland, Massachusetts is 4650 cfs and 45 mgd (70 cfs), when the flow is more than 4,650 and less than 4,900 cfs.

These findings of the Secretary of War regarding operational schedules for the diversions were later made a part of the Supreme Court Decision, dated March 1931, in the suit between Connecticut and Massachusetts. Since the date of that decision, diversions from the Swift and Ware Rivers have been accomplished under the Secretary of War's findings.

During the progress of the NEWS Study, an interested citizens' group suggested the setting aside of the Swift River diversion limitations with the objective of retaining presently scheduled releases within Quabbin Reservoir. The citizen group further suggested any diminution of flow in the Connecticut River could be made up by releases from existing Corps of Engineers' flood control reservoirs. In keeping with this suggestion, an examination of the potential which such rescheduling might have on the short-range supply problems was made.

The drainage area of the Swift River controlled by the Quabbin Reservoir is 186 square miles. The long-term average annual runoff from the watershed is 187 mgd (289 cfs) of which 32 mgd (50 cfs) has been released downstream in compliance with the existing downstream release schedule.

Thus, the maximum addition to the existing water supply system which could be achieved through re-scheduling would be 32 mgd (50 cfs). To provide this increment, however, all downstream release would have to be terminated. Such a complete cessation of downstream releases with the subsequent "drying up" of the river reach downstream is, of course, impracticable. The question then raised is what level is practicable. A recent study[1] completed for the entire Connecticut River Basin recommends an instantaneous discharge rate, from power reservoirs on the Connecticut River of 0.25 cubic feet per second per square mile of upstream watershed. An application of this criteria to Quabbin Reservoir, for example, would result in a downstream release requirement of 30 mgd (46 cfs). Adoption, then, of such a modified operational schedule could result in an additional 2mgd being made available. This increment of yield, however, would not begin to meet the short-range needs of this report's study area which are estimated to total an additional 141 mgd. In short, then, a re-examination of downstream release schedules with the objective of conserving such releases for water supply has merit. However, based on the requirement of maintaining a viable river environment downstream from Quabbin, the opportunity for reducing downstream releases does not offer an alternative to the project reported upon in this study.

The spring runoff which occurred in 1972 was of longer duration and of greater magnitude than is usually experienced. As a result, diversions from the Ware River, in compliance with the operation schedule described earlier, were forced to cease even though flows in excess of 85 mgd were still occurring. This event triggered a suggestion to the NEWS Study that if the 15 June to 15 October no diversion constraint were lifted, large additional supplies of water could be made available to Quabbin.

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1 Comprehensive Water and Related Land Resources Investigation, Connecticut River Basin, Connecticut River Basin Coordinating Committee, June 1970.

A computer test was made to determine the impact of the 15 June to 15 October constraint. The results of the computer simulation indicated that only an additional 2.6 mgd might be made available if the 4 month no diversion period currently in effect were terminated.

In the Ware River, as in the case of the Swift River, a re-examination of downstream release schedules may have merit. However, terminating the 15 June to 15 October diversion period constraint does not offer an alternative to the proposed diversion projects.

Local Resource Potential

In estimating needs which might be required of the existing regional supply system (MDC), the role which locally available resources might play was investigated. The majority of new communities reported in this study as requiring connection to the regional system to meet future needs was the result of engineering studies conducted by the Metropolitan Area Planning Council (MAPC). The MAPC comprises 98 municipalities in the Boston Metropolitan Region which includes the majority of presently serviced MDC communities and the MDC's future short-range customers.

The purpose of the study was to identify and evaluate alternative water supply systems which may be developed to satisfy the water supply demands of the communities in the Council District through the year 1990. These systems would supplement the existing and potential local supply systems. The need for supplementing the existing supplies of most of the communities within the District was concluded from investigations conducted in conjunction with the 1969 Needs and Proposals[1] report.

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1 Projected Needs and Current Proposals for Water and Sewer Facilities, July 1969, Metropolitan Area Planning Council by Camp, Dresser & McKee.

These investigations indicated, that of the 98 communities in the Council, only two communities had existing supplies capable of meeting projected 1990 demands, and only 17 communities outside of the communities served by the Metropolitan District Commission (MDC) reported potential supplies which, together with the existing supplies, could meet the 1990 demands.

The supplemental water systems discussed were developed along criteria and design guidelines chosen to be sufficiently generalized to permit use throughout the District, yet detailed enough to produce systems which were technically sound. The efficient development of a water supply system to meet the projected demands of the communities within the Council District will require further detailed studies of the most favorable alternatives presented in this study. All systems were developed without regard to institutional constraints. Particular emphasis was placed on the development of subdistrict systems which would serve a portion of the Council District through the utilization of local resources.

The supplemental needs of the individual communities were determined by comparing projected demands with the estimated safe yield of the existing and potential community supplies. Needs were assessed in accordance with the study policy that all local potential supplies were to be developed. The needs may change in time as additional potential local supplies are discovered, or potential supplies must be abandoned. It is emphasized that all potential groundwater sources must be fully explored, and development seriously considered even though the water is of quality that will require treatment.

The majority of the supplies to be developed to supply the subdistrict system will be surface supplies with either on or off stream reservoirs. It is imperative that before any of these alternatives are adopted, studies be conducted to investigate fully the environmental implications of these diversions.

In summary, the potential for local resource development as an alternative supplementing the existing regional supply system was examined. In some regions, particularly outside of the Boston Metropolitan Area, local resources are available which can meet future needs. In the Boston Metropolitan Region, however, there are a number of communities who will require connection to the larger regional system to meet forecast demands. In turn, the regional system requires augmentation of its supply sources to enable it to meet the needs of present customers and those other communities which do not have available local resources.

Population Zoning and Regulations

Limitation of population influx in a given area requires major social and political changes before zoning legislation can be effected. There is also a question of constitutionality to the principal of population zoning. If enforced, zoning will reduce population and industrial growth and, therefore, create population and water problems elsewhere. Before population regulation can be taken seriously, major political, social and religious considerations must be resolved.

6. The Relationship Between Short-Term Uses of Man's Environment and The Maintenance of Long-Term Productivity

Simply stated, the diversion of water envisioned by these projects would constitute a long-term use of some of the donor areas resources for the long-term productivity of the receiver area. The planning process, which included extensive engineering studies and an assessment of the biological and environmental data accumulated during the study period, did not uncover any irreversible actions or drastic effects on the area environment. It did, however, bring forth findings discussed elsewhere in this report which represent "trade offs" which are the alternates of two or more courses of possible action. Even by attempting to clearly delineate these points it was found that words which have acquired a specific connotation in relation to the study become a major problem in interpretation. The phrase, "flood skimming" is a case in point. In its original sense it was used to denote a course of action to divert water in the spring during the high flow period. It was as it has turned out, an unfortunate choice of descriptive words because it has led to an erroneous opinion that the total volume of the "flood waters" will be "skimmed". In actuality, for example, the Connecticut River under the proposals discussed in this draft would lose 2 3/8" of elevation at Montague City at the maximum diversion rate. This small loss in elevation would be unnoticeable to the casual observer.

It should be pointed out that both donor and receiver areas are within the borders of Massachusetts, so that economic benefits realized by the construction of the project would be reflected favorably on the state's economy as a whole.

7. Irretrievable or Irreversible Commitment of Resources

All of the actions considered during the course of these studies would commit time and money. Further, structural measures would involve the commitment of materials to build the projects and would require the pre-empting of specific sites for other uses. Creation of weirs, tunnels, aqueducts and other fixed structures will commit these sites to long-term changes in present land use patterns. The precise extent of this commitment is unknown at this planning stage, but the impact can be minimized in the detailed project planning stage and by such tools as local land use and zoning. Nevertheless, although minor, it is a commitment to be recognized at this time.

Alterations to the landscape may also have an impact on those species of birds which pass through on their migration or remain to nest and raise their young. No known endangered species of birds or animals utilize the proposed project lands. The amount of nesting habitat for migratory species will remain essentially the same in the region as it is at present.

In the strictest sense none of the proposals cause an irretrievable loss of resources. The rivers will still be there and water can be returned to the ocean by the original pathways. Structures can be removed and the land restored to its former condition. In summary, the projects will not bring about changes in land or water use which could not be halted or reversed.

8. Coordination With Other Agencies

Drafts of this Statement are being furnished to Federal, State, and Local agencies, as noted on the Summary Sheet, which have particular expertise or interest in the project. Their comments will be used in the revision of this statement and incorporated in the final statement, as will responses of other interested parties who care to respond within the forty-five day review period.

Public Law 89-298
89th Congress, S. 2300
October 27, 1965

An Act

Authorizing the construction, repair, and preservation of certain public works on rivers and harbors for navigation, flood control, and for other purposes.

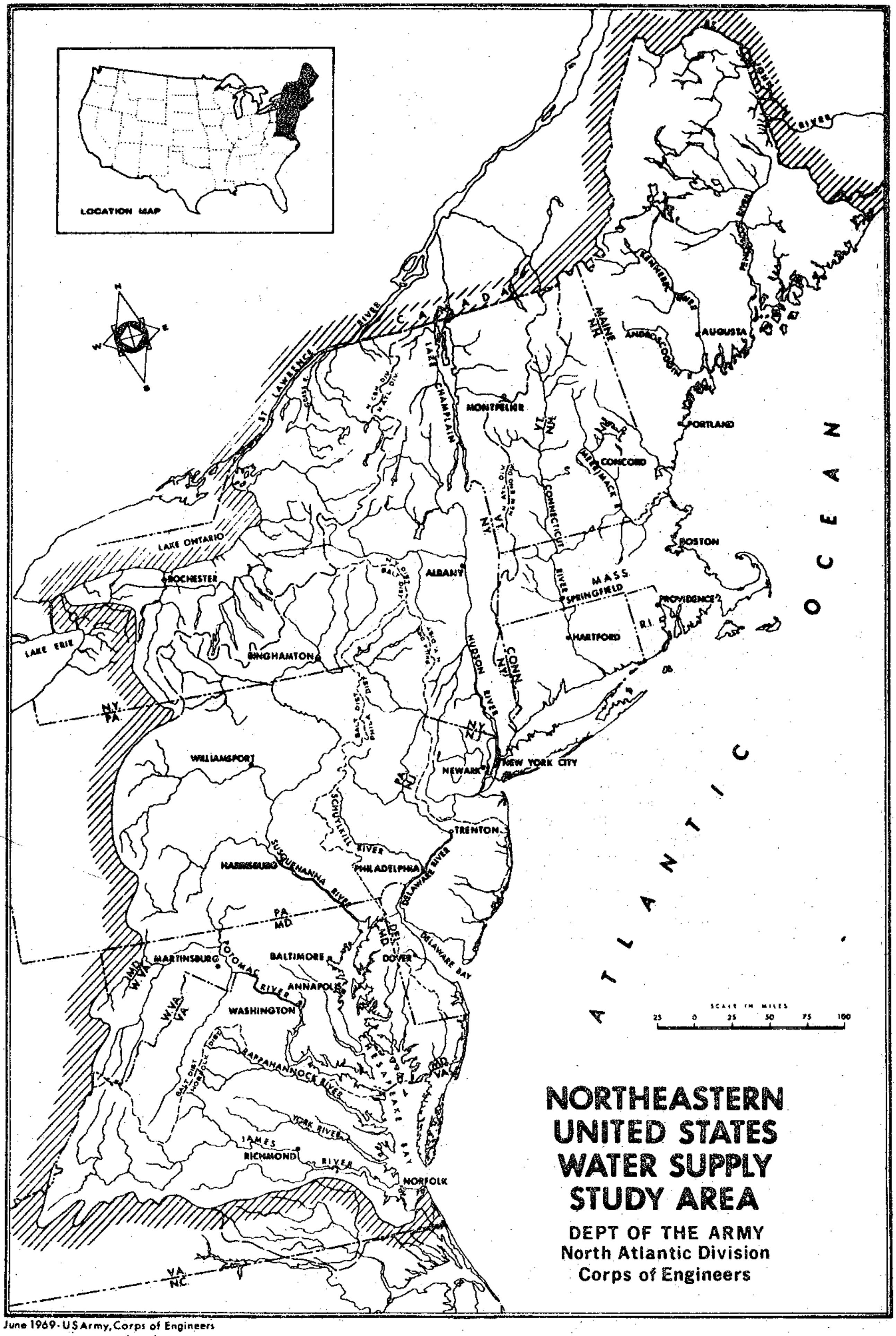
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

TITLE I—NORTHEASTERN UNITED STATES WATER SUPPLY

SEC. 101. (a) Congress hereby recognizes that assuring adequate supplies of water for the great metropolitan centers of the United States has become a problem of such magnitude that the welfare and prosperity of this country require the Federal Government to assist in the solution of water supply problems. Therefore, the Secretary of the Army, acting through the Chief of Engineers, is authorized to cooperate with Federal, State, and local agencies in preparing plans in accordance with the Water Resources Planning Act (Public Law 89-80) to meet the long-range water needs of the northeastern United States. This plan may provide for the construction, operation, and maintenance by the United States of (1) a system of major reservoirs to be located within those river basins of the Northeastern United States which drain into the Chesapeake Bay, those that drain into the Atlantic Ocean north of the Chesapeake Bay, those that drain into Lake Ontario, and those that drain into the Saint Lawrence River, (2) major conveyance facilities by which water may be exchanged between these river basins to the extent found desirable in the national interest, and (3) major purification facilities. Such plans shall provide for appropriate financial participation by the States, political subdivisions thereof, and other local interests.

(b) The Secretary of the Army, acting through the Chief of Engineers, shall construct, operate, and maintain those reservoirs, conveyance facilities, and purification facilities, which are recommended in the plan prepared in accordance with subsection (a) of this section, and which are specifically authorized by law enacted after the date of enactment of this Act.

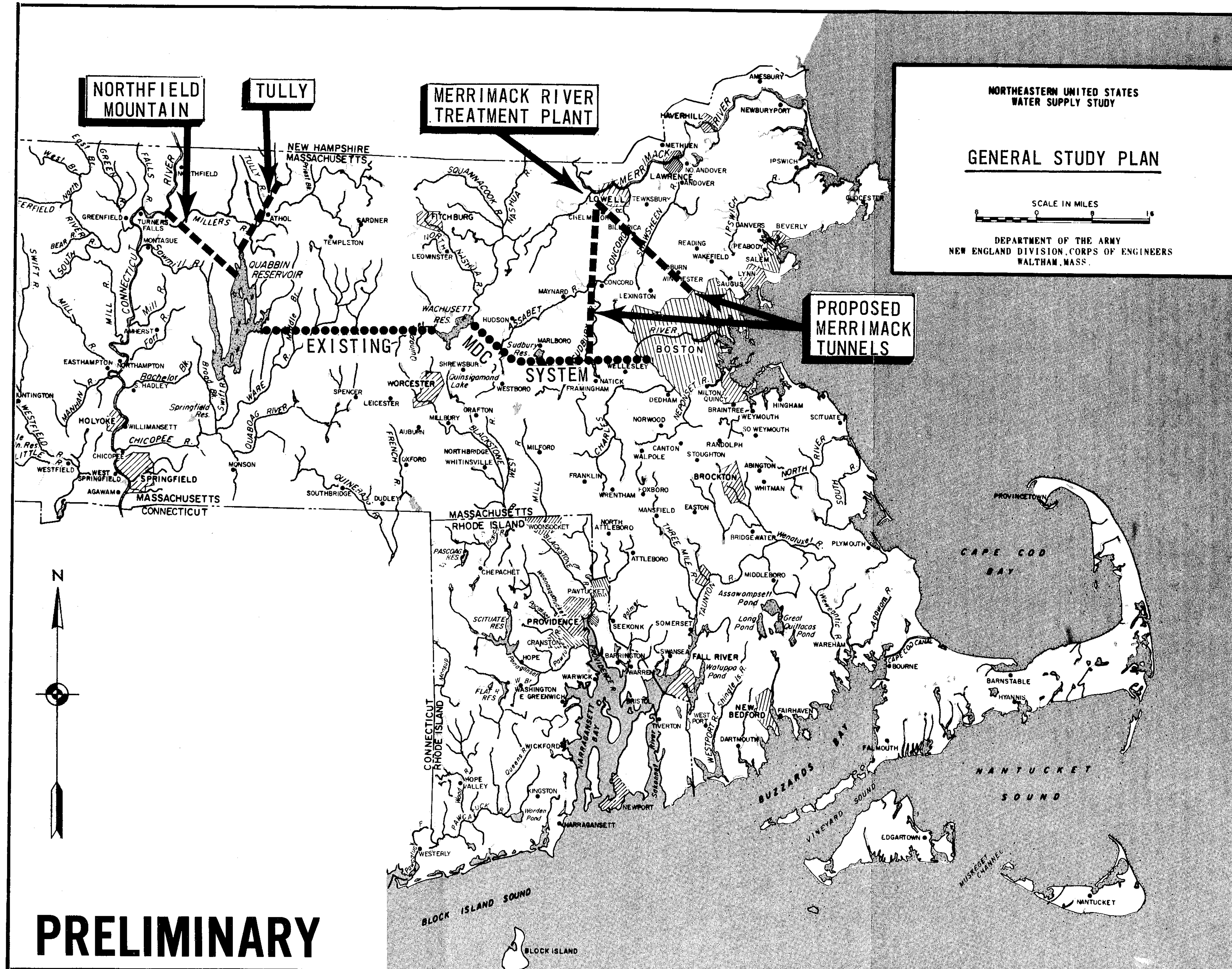
(c) Each reservoir included in the plan authorized by this section shall be considered as a component of a comprehensive plan for the optimum development of the river basin in which it is situated, as well as a component of the plan established in accordance with this section.



NORTHEASTERN UNITED STATES WATER SUPPLY STUDY AREA

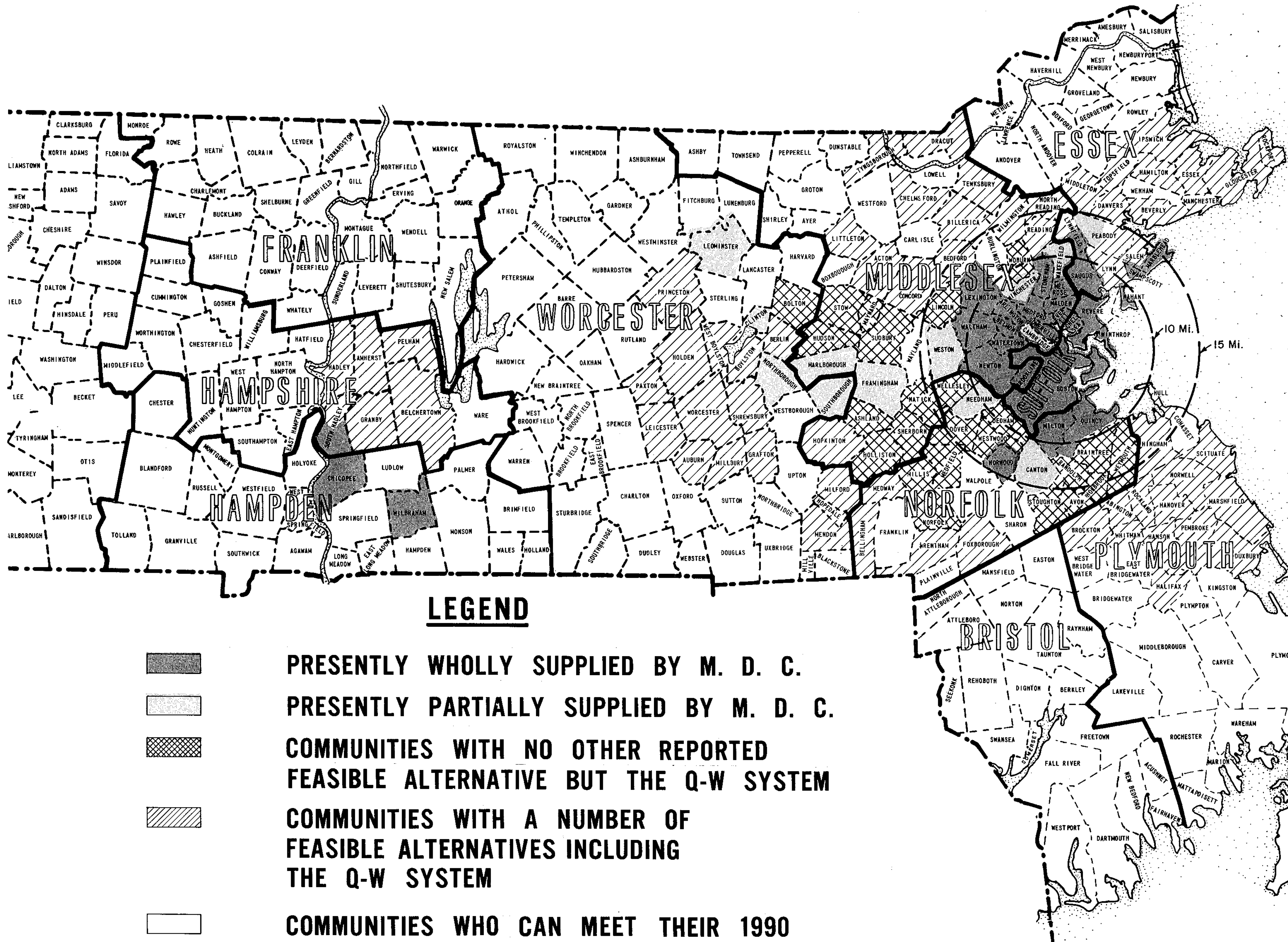
DEPT OF THE ARMY
North Atlantic Division
Corps of Engineers

June 1969 - US Army, Corps of Engineers



NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
GENERAL STUDY PLAN
SCALE IN MILES
DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
NORTHFIELD MOUNTAIN
TULLY
MERRIMACK RIVER TREATMENT PLANT
PROPOSED MERRIMACK TUNNELS
EXISTING MDC SYSTEM
QUABBIN RESERVOIR
WACHUSETT RES.
BOSTON
NEW HAMPSHIRE
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
CAPE COD BAY
NANTUCKET SOUND
BUZZARDS BAY
BLOCK ISLAND SOUND
N
PRELIMINARY

CORPS OF ENGINEERS U. S. ARMY



LEGEND

PRESENTLY WHOLLY SUPPLIED BY M. D. C.

PRESENTLY PARTIALLY SUPPLIED BY M. D. C.

COMMUNITIES WITH NO OTHER REPORTED FEASIBLE ALTERNATIVE BUT THE Q-W SYSTEM

COMMUNITIES WITH A NUMBER OF FEASIBLE ALTERNATIVES INCLUDING THE Q-W SYSTEM

COMMUNITIES WHO CAN MEET THEIR 1990 DEMANDS FROM LOCAL SOURCES OR OTHER REGIONAL SYSTEMS

EXISTING Q-W SERVICE AREA

PROBABLE 1990 Q-W SERVICE AREA

POSSIBLE 1990 Q-W SERVICE AREA

PRELIMINARY

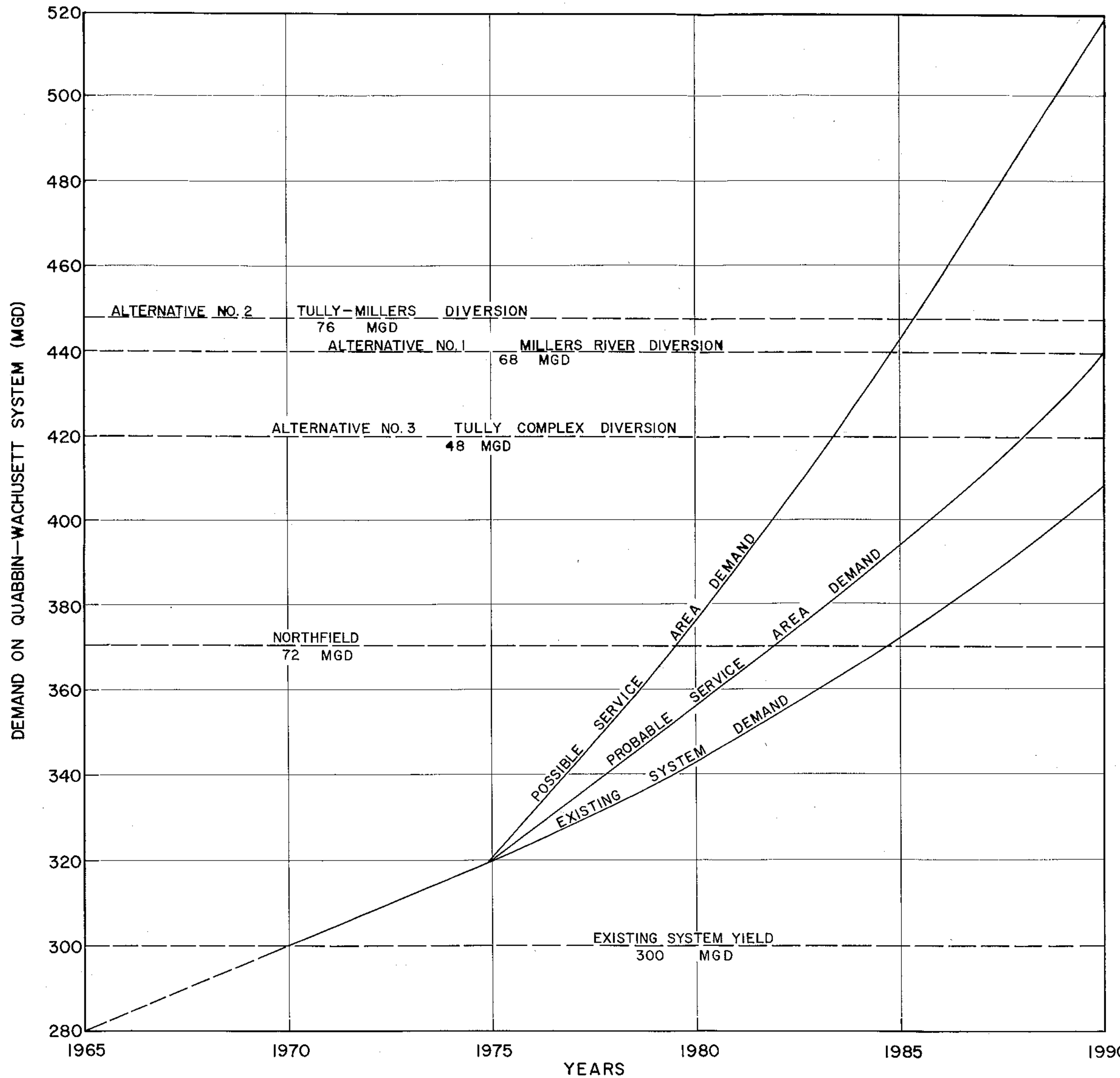
REVISION	DATE	DESCRIPTION	BY

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
MILLERS RIVER BASIN
QUABBIN-WACHUSETT
WATER SUPPLY SYSTEM
EXISTING AND FUTURE SERVICE AREA

DES. BY | DR. BY | CK. BY
SUBMITTED:
CHIEF, SECTION
APPROVAL RECOMMENDED:
CHIEF, TECH. ENG. BRANCH
REVIEWED:
PROJECT ENGINEER
APPROVAL RECOMMENDED:
CHIEF BRANCH
APPROVED DATE
CHIEF, ENGINEERING DIVISION
SCALE | SPEC. NO.
DRAWING NUMBER
SHEET

CORPS OF ENGINEERS — U. S. ARMY



LEGEND:
— — — HISTORICAL DEMAND
——— PROJECTED DEMAND

GRAPHIC SCALES

PRELIMINARY

REVISION	DATE	DESCRIPTION	BY

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION
CORPS OF ENGINEERS
WALTHAM, MASS.

DES. BY — DR. BY J.Z. — CK. BY

SUBMITTED: CHIEF, SECTION

APPROVAL RECOMMENDED: CHIEF, TECH. ENG. BRANCH

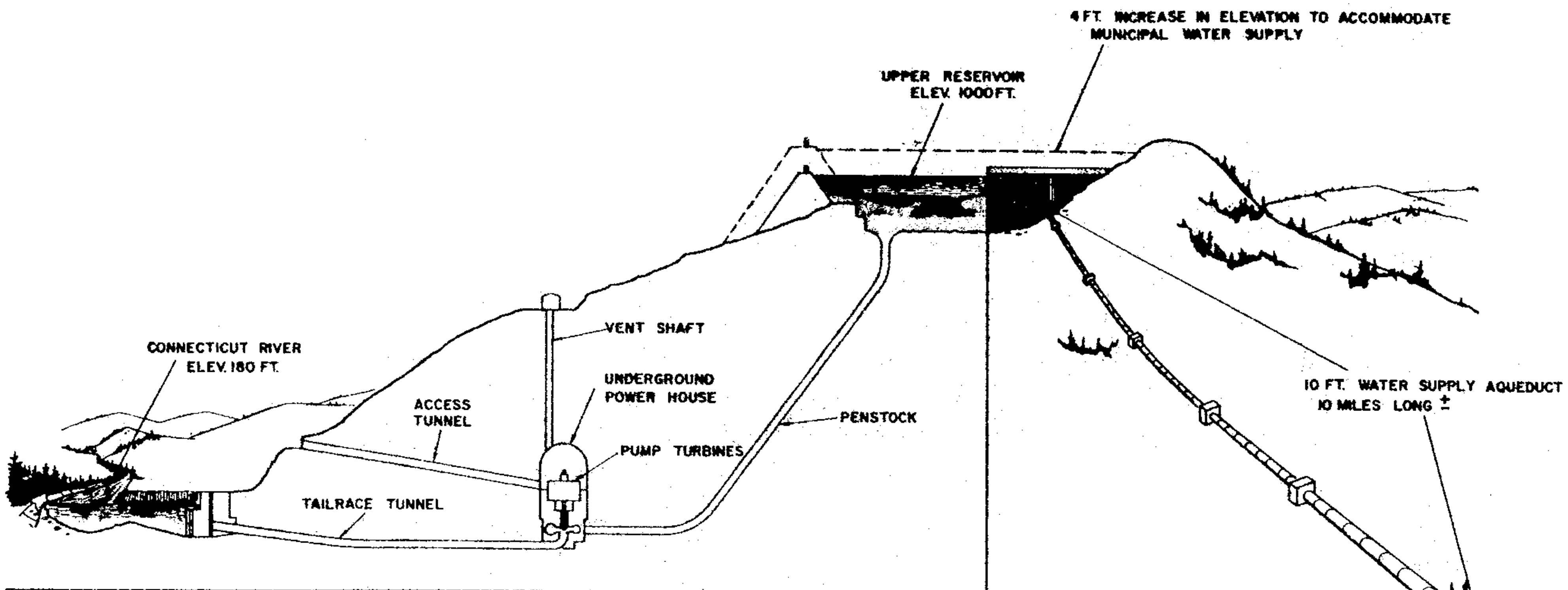
REVIEWED: PROJECT ENGINEER

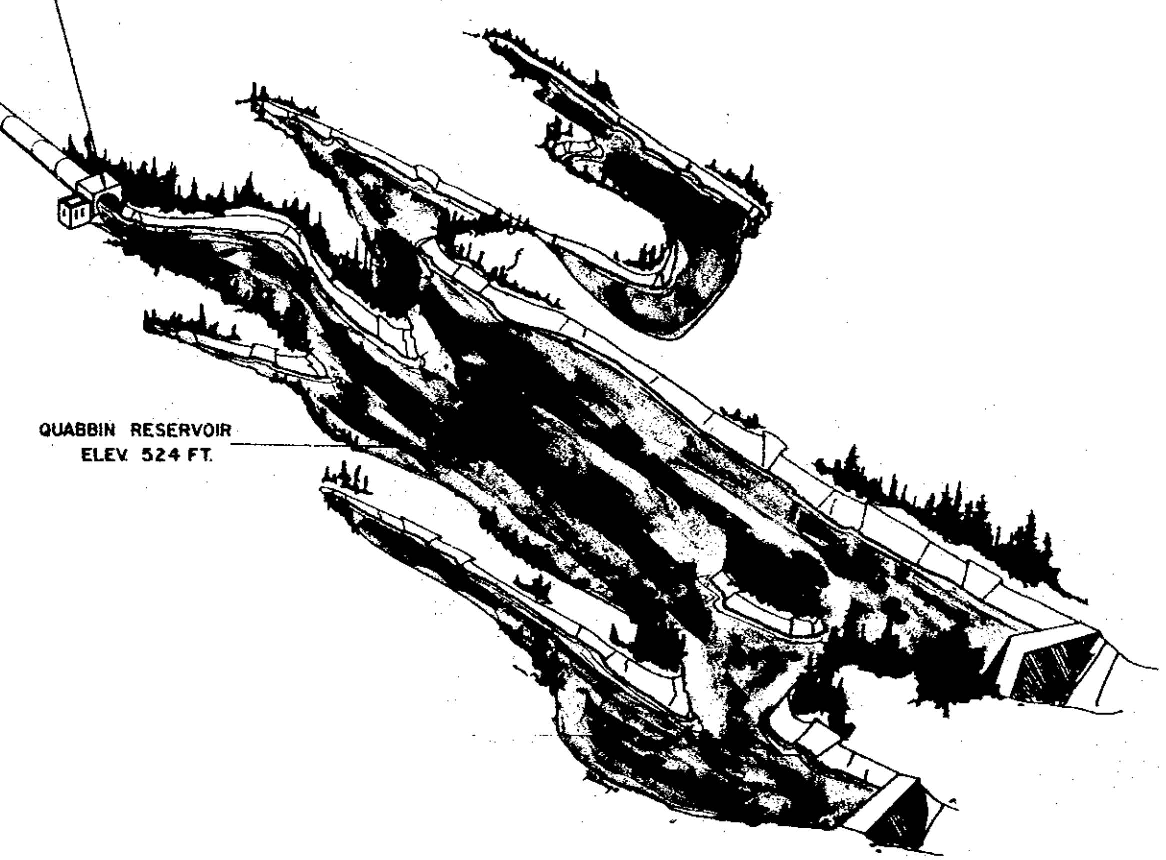
APPROVAL RECOMMENDED: CHIEF BRANCH

NORTHEASTERN UNITED STATES
WATER SUPPLY STUDY
MILLERS RIVER BASIN
ESTIMATED DEMAND ON
QUABBIN — WACHUSETT SYSTEM

APPROVED — DATE
CHIEF, ENGINEERING DIVISION

SCALE — SPEC. NO.
DRAWING NUMBER
SHEET





NORTHFIELD MOUNTAIN PROJECT
PROPOSED MULTI PURPOSE USE
POWER GENERATION - WATER SUPPLY

PRELIMINARY